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# ENERGY MONITORING AND CONTROL SYSTEMS EFFECTIVENESS AND EFFICIENCY

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LSSR 7-78B

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Energy Monitoring and Control Systems have been installed at numerous Air Force bases to reduce energy consumption and save operations and maintenance cost. However, Congress has been concerned with the actual results of the systems and is skeptical of the cost and savings estimates used to justify appropriation of funds for these systems. This study examines the effectiveness and efficiency of operational EMCS to determine if they meet current cost and energy savings criteria; determines if Architect-Engineer feasibility study cost and savings estimates used to justify the systems to Congress are accurate; and determines if there is an easier way than the detailed and costly feasibility studies to estimate the EMCS cost and savings. The study concludes that the current EMCS do meet the current cost and energy savings criteria and the Architect-Engineer feasibility study cost and savings estimates are accurate. The study did not find an easier way to estimate the EMCS cost and savings than the feasibility study method.

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# ENERGY MONITORING AND CONTROL SYSTEMS EFFECTIVENESS AND EFFICIENCY.

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

By

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This thesis, written by

Captain Allen A. Alchian

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has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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## INTRODUCTION

### Background

The rapid rise in energy and manpower costs since 1973 and the increased dependence on foreign oil (currently 50 percent of all oil used in the United States is foreign oil (20:1-1)) led to the development of Executive Order 12003, 20 July 1977 (30:2-3). This Executive Order requires that all Federal Agencies reduce energy consumption in existing facilities by 20 percent by 1985. The Executive Order further requires that new facilities will use 45 percent less energy than was used in facilities during 1975. One way to reduce energy consumption and operations and maintenance costs in facilities is to use a computer controlled system to eliminate manual operations and to optimize the operation of mechanical and electrical systems. The Air Force calls this system an Energy Monitoring and Control System (EMCS) (21:16-21).

### Problem Situation

Fifteen million dollars was appropriated by Congress during Fiscal Year (FY) 1978 to install or expand Energy Monitoring and Control Systems (EMCS) at seventeen military bases in the United States (37:H8504-6). During the FY

1978 appropriations hearings, Congress made repeated requests for the services to provide actual operating data on previously authorized EMCS. At the conclusion of the hearings, the House conferees reported:

> The conferees agreed to include some but not all of the energy control and monitoring projects approved by the Senate. The House conferees feel that more testing of actual systems is required to verify that these systems actually live up to the services' expectations and to validate both the total concept and the specific applications of these systems [37:H8504].

Problem Statement

It is not known if the existing Air Force EMCS provide significant energy and economic savings. It is also not known if the cost and savings estimates used to justify appropriation of funds for installing an EMCS are accurate.

Early EMCS Concepts

The use of an EMCS for monitoring and control of facility systems is not a new concept. The first systems were used over 30 years ago to monitor and control the operation of large facilities (32:II-1). The systems were used to reduce the work force necessary to operate and maintain the facility. These early systems (Central Supervisory Control Systems) consisted of hardwired, as opposed to today's software programmable, central control units. Each sensor and control was individually connected to the central control unit by wires or pneumatic lines.

The main functions of the system were to monitor the various conditions of the facility such as temperature, humidity, pressure, fire alarms, and security alarms; and to be able to control the operation of equipment such as air-handling units, air-conditioning units, heating units, water pumps, elevators, etc. The system would eliminate the need to send men around to check or change the operation of the equipment. Because of the large expense of these initial systems, they were only used in large complex facilities such as hospitals, complex laboratories, or high-rise buildings (32:II-1).

The monitor and control systems evolved during the late 1960's to include some automatic functions controlled by a more sophisticated electronic central control unit. The savings from these systems increased as the cost of labor increased during this period. This allowed the systems to be used in more facilities (32:II-2; 13:80). The Air Force started to use these systems in hospitals, complex laboratories, and for base-wide security and fire alarm systems. Some examples for these early systems are shown in Table 1-1 (6).

## Advanced EMCS Concepts

After the 1973 oil embargo and rapid rise in energy costs, the manufacturers of the systems developed more applications within the EMCS for controlling energy consumption. The manufacturers started to use data

TABLE 1-1

Early Air Force EMCS

| Base | System | Purpose | Cost | Year Installed |
|---|---|---|---|---|
| Hill AFB | Honeywell Delta 2000 | Fire Alarms | $280,000 | 1973 |
| Kelly AFB | Johnson T-6700 | Monitor & Control Chilled Water Plant | $365,000 | 1973 |
| Mather AFB | Powers Custom | Hospital | $ 65,000 | 1970 |
| Nellis AFB | Robertshaw MLS 200 | Hospital | $ 17,500 | 1970 |
| Tinker AFB | Honeywell Alpha 300 | Fire Alarms | $457,460 | 1974 |
| Wright-Patterson AFB | Honeywell System 6 | Hospital | $ 75,000 | 1964 |
| Wright-Patterson AFB | Barber-Coleman | Avionics Laboratory | $400,000 | 1971 |

multiplexing techniques to eliminate the need for a single communications line for each sensor and control. They added a mini-computer to the central control unit to give the system the capability to make calculations and issue commands based on the results. The new technology lowered the cost of the systems while providing for increased energy and manpower savings. The EMCS were subsequently used in all types of facilities in both the private and public sectors. The lower cost of the systems and greater savings realized made it possible to economically use one system to monitor and control either thousands of sensors and controls scattered throughout an Air Force base or just a few sensors and controls in one small facility (3:97-104; 7:1-2; 10:80-86; 32:II-2; 39:20-27).

The Air Force started to install these new systems during 1974-1976 to monitor and control energy consumption in base facilities. The first systems used automatic start/stop and load shedding programs[1] for energy conservation because it took only one control and a simple program to save a large amount of energy. These systems also included many monitoring only functions that could save energy indirectly by sensing problems and sending an alarm to the central control operator. The operator could then take action from the central control unit if the equipment

[1]A description of the different functions is in Chapter 2 of this research effort.

in the facility was connected to the EMCS or else he could notify a maintenance crew to check the problem. Many of the other features (changeover, resetting, optimization, etc.)[1] of the EMCS were not used initially because they required connecting many additional sensors and controls that would increase the cost of the system and not provide as great a savings as the start/stop feature. The large savings from the start/stop feature resulted from changing the normal 24 hour/day operation of the equipment to only 10-12 hours/day. While time clocks could do the same thing, they required many hours of maintenance to insure that they were operating properly. With reduced manpower in Civil Engineering, time clocks were eventually taken off the line by repairmen rather than taking the time to fix them. Thus, the EMCS provided a way to insure the start/stop operation would always be current and also provide the capability to do many more functions as the funds became available (3:97-98; 39:20-22).

Air Force EMCS Project Funding

The approval for these early systems by Congress was based on savings calculations made by Civil Engineering personnel. They usually used manufacturer's data or designs of other systems made by Architect-Engineer (A-E)

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[1]A description of the different functions is in Chapter 2 of this research effort.

firms. The A-E firms designing the systems after approval also received most of their savings and cost data from the manufacturers because the manufacturers had the only experts in the field at this time. Many of these first systems were installed as part of major facility construction projects in order to get a system started at a base (31:1). Therefore, the systems were justified based on total life cycle costs and not just energy conservation savings. By the end of 1975 there were 26 systems in operation in the Air Force at a total installation cost of $5,322,500 and another 13 projects under construction at a cost of $4,841,000 (6). The total value of the systems was not high in comparison to either the total facility value or energy cost in the Air Force, but it was increasing at a very rapid rate.

The increase in cost of the EMCS and other energy conservation projects prompted Congress to set up a separate identification of energy conservation projects in the military construction appropriation process. This program was called the Energy Conservation Investment Program (ECIP). It was set up during the FY 76 Military Construction Program to control the cost of energy conservation projects and provide a method to allow the energy conservation projects to compete among themselves instead of with other military construction projects. The ECIP projects required calculations of energy and manpower

savings versus the investment cost (payback). Initially, the criterion was that the EMCS payback had to be reasonable (11:1). However, as the cost of ECIP projects continued to increase, stricter criteria were needed to insure only the projects that had a good payback and energy savings were approved.

The criteria for FY 79 ECIP projects are at most a six year payback and an annual energy savings of at least 23 million Btu[1]/$1000 invested (14:2). Because of the increase in the cost of the projects, concern over the application of the ECIP projects increased. The United States General Accounting Office (GAO) started to investigate the application of Energy Conservation Investment Program funds and the validation of estimated energy and manpower savings (12:1). During the same time, 1976, the major commands started to take an active interest in the EMCS projects because of reports from their bases of problems with the initial systems being installed at their bases.

Air Force EMCS Problems

The application of EMCS systems to many facilities with different functions was creating problems. Previous systems were limited to single complex facilities or one

---

[1]Btu--British termal units--The amount of energy required to raise the temperature of one pound of water one degree Fahrenheit.

function (fire or security alarms) applied to many facilities. The Air Force and Architect-Engineers did not have the expertise necessary to properly determine what functions to include, how to design the systems, or how to effectively determine the savings. The manufacturers were also experiencing problems because, in many cases, they did not participate in the design of the system that was included in the contract documents. Thus, when they bid on the contract they usually did not have a good idea of what was wanted or what equipment would be required. This led to problems once a manufacturer started to install their equipment. Also, the air-conditioning and heating controls in the facilities frequently were not operating as originally designed because of changes or temporary modifications made in the field. These problems led to ineffective and inefficient EMCS operation during 1973-1976.

The Air Force major commands decided to jointly discuss these problems and develop a set of specifications for an Air Force EMCS. During 7-10 December 1976, the Air Force EMCS Guide Specifications Workgroup discussed these problems. Each major command representative presented their experiences and recommendations. The experiences and recommendations of the Strategic Air Command (SAC) were:

> . . . Design statements easily become proprietary, limit manufacturers from bidding who are truly honest in meeting the specification requirements, and limit technical advance in the field . . . . We have also

> found some changes to existing mechanical systems and controls must be accomplished before EMCS can produce energy savings . . . . Our conclusion from dealing with the Architect-Engineers is that most of them are inexperienced in the EMCS point selection and have difficulty in putting monetary justification against point selection . . . . Also, we have experienced some problems with Base Procurement insisting on small business on EMCS rather than opening bids to all . . . [38:3C-1 to 3C-4].

The early EMCS experiences of the Air Force Systems Command (AFSC) included "exposure to 'EMCS' - not; however, as a prime means of avoiding the waste of energy [38:3D-1]." Thus, AFSC was initially not using the EMCS to save energy but to monitor facility systems. The Air Force Logistics Command (AFLC) experience included:

> . . . The largest problem is getting adequate funds for our bases . . . . AF is reluctant to spend large amounts of money at one time. We can only get the basic console, and four to six buildings on the first project and expand on follow-on projects. However, once we have a basic system, we are stuck with the one manufacturer, because it is difficult to get a follow-on project from a different manufacturer, if we already have the complete console . . . . Our system was installed at Hill AFB for fire alarms, and the reliability was just to demonstrate operation, one-time. We had 20 points down per day over the last nine months . . . . We have also had problems with lightning strikes inducing surges in the sensor lines and burning out the cards in the gathering panels at Robins . . . . The A-E's that made our first studies knew little more than we did about EMCS. They showed unrealistic savings for some points, and none for points with large savings. Our initial estimates were based on manufacturer's data and the A-E's estimates were two-to-three times as much . . . . All of our present installations were part of other projects [38:3E1-3E6].

The Military Airlift Command (MAC) experience was the following:

Our experience, and that of Headquarters Command, from whom we inherited Andrews and Bolling AFB's, was initially bad. We have Johnson systems at Bolling and Andrews, neither of which are operating. We have a Honeywell system at Charleston which became inoperative after expiration of the warranty [38:3F1-3F6].

These problems showed that (1) there were no experts in the field and engineers designing the systems were still in the early learning stages which resulted in numerous deficiencies; (2) the equipment was not as reliable as the manufacturers estimated; (3) the EMCS required that the equipment it was to control must be operating properly; (4) the communications system had to be of good quality and protected from induced voltages; and (5) the Air Force engineers had to become EMCS experts immediately in order to resolve these problems (30). The GAO's preliminary investigation of the EMCS also found these problems. A GAO letter dated 11 March 1977 to the Acting Assistant Secretary of Defense (Installation and Logistics) stated:

> . . . Defense installations are procuring or expanding 29 systems in fiscal year 1977 at an estimated cost of about $30 million but they have not drawn up performance specifications tailored to their particular needs . . . . Certain Navy and Air Force officials told us that buying systems built to the manufacturer's specifications resulted in receiving outmoded technology and in negotiating with a single manufacturer for the system, system programs, and future system expansions . . . .
>
> We believe that
>
> --Adequate specifications and advertised procurement will promote competition and may result in acquiring the most efficient systems at the lowest costs.

--Better coordination and planning are necessary to take advantage of joint use of systems and avoid unnecessary system duplication.

--Systems are being funded with energy conservation investment funds but achieving savings that are not primarily energy oriented [23:1-3].

Current EMCS Status

The GAO findings and the FY 78 Congressional hearings stated that actual operating data were needed to validate the effectiveness and efficiency of the EMCS. The experience from the Air Force EMCS Guide Specifications Workgroup indicated that the actual operating data may show that the systems were not living up to the claims made by the manufacturers. As a result of the problems experienced and the Congressional hearings, the FY 79 EMCS projects will require revalidation and economic analysis during the design stage. Also, actual operating data from existing systems are required for the FY 79 MCP Congressional hearings. Collection of actual operating data for the systems approved during fiscal years 1976 and 1977 cannot be accomplished at this time because the systems are not yet operating; therefore, an analysis of actual operating data for these systems cannot be performed until they are completed (13:1).

To date there has been no statistical analysis of actual operating data from existing Air Force EMCS to determine if they are effective and efficient. The analysis performed to date consists of engineering estimates or

computer simulations before the systems are installed. The latest available computer simulation was performed by Headquarters Air Force Logistics Command, Engineering and Services, at Wright-Patterson AFB, Ohio, as part of the Building Energy Audit Pilot Program (BEAPP) (15:1-93). The BEAPP was developed to determine the best method to implement Executive Order 12003 (30:2-3) to reduce existing energy consumption in facilities by 20 percent. EMCS control of the facility equipment was recommended for most of the facilities. Table 1-2 shows some of the savings and cost estimates from the BEAPP (15:6-7). However, engineering estimates or simulation programs will not show the actual savings achieved by using an EMCS.

Research Objectives

This research effort had three objectives. First, the existing operating data from Air Force EMCS were analyzed to determine if they meet the current Air Force criteria of at least six years payback and a minimum annual energy savings of 23 MBtu[1] per $1000 invested. Second, the feasibility study estimates prepared by Architect-Engineer firms used to justify the EMCS installations were analyzed to determine if they accurately predicted the energy saved, the net operations and maintenance cost saved, and the EMCS initial cost per

[1]MBtu: Million Btu

TABLE 1-2

Building Energy Audit Program Recommendations
For Wright-Patterson AFB, Ohio

| Building Number | Recommended Project | % Energy Reduction | Cost ($000) | Years Payback |
|---|---|---|---|---|
| 20014 (Admin) | EMCS Control | 37 | 27.0 | 3.0 |
| 20050 (Admin) | Space Temperature Reset by EMCS | 48 | 16.5 | 4.7 |
| 20485 (Avionics) | High Efficiency Dampers, EMCS | 56 | 29.1 | 1.0 |

facility on an Air Force base. Third, Multiple Linear Regression (MLR) models were developed and tested against the actual operating data to determine if they could provide an easier way to predict the actual savings and cost from installing an EMCS on an Air Force base.

## Research Hypotheses

1. An EMCS can provide a payback of less than six years and an annual energy savings of at least 23 MBtu per $1000 invested.

2. The Architect-Engineer (A-E) feasibility studies accurately predict the energy saved, the net operations and maintenance cost saved, and the EMCS initial cost per facility.

## Research Question

Can Multiple Linear Regression (MLR) models be used to accurately predict the actual energy saved, net operations and maintenance cost saved, and EMCS initial cost per facility on an Air Force base?

## Scope and Delimitations

The scope of this research included all Air Force installations in the United States. The scope was limited to the Air Force because the literature review did not reveal any detailed information on EMCS that is readily available. Therefore, in order to gather data on the EMCS, organizations would have had to be contacted on an

individual basis to request the data required. An effort to gather data from different organizations could have been useful in comparing the different organization's use of the EMCS against each other; however, the time and effort would have been excessive for this research effort. Therefore, the effort was limited to just EMCS installed at Air Force bases in the United States.

## Chapter 2

## ENERGY MONITORING AND CONTROL SYSTEMS

### System Development

The EMCS being manufactured today provides a wide variety in functions and capabilities. The basic configuration of the EMCS is shown in Figure 2-1. This configuration differs from the original equipment used 30 years ago. The original equipment had a simple control unit and all sensors and controls were connected directly to it. The equipment used during the late 1960's and early 1970's added Field Interface Devices (FID) that allowed data multiplexing (using a single transmission line to send and receive data from many devices). The early FID's could only determine which control device was to get a signal from the central control unit or which sensor's signal was to be sent to the central control unit. Also, the central control unit did not have a computer. It had a hardwired logic unit that required changes in the hardware to change or add functions. The equipment manufactured today added electronic technology developed during the 1970's similar to the calculator industry (more capability with smaller components at less cost) (32:II-1 to II-6; 29:53-59). The EMCS described on the following pages was summarized from the Civil Engineering Center "Energy Monitoring and Control

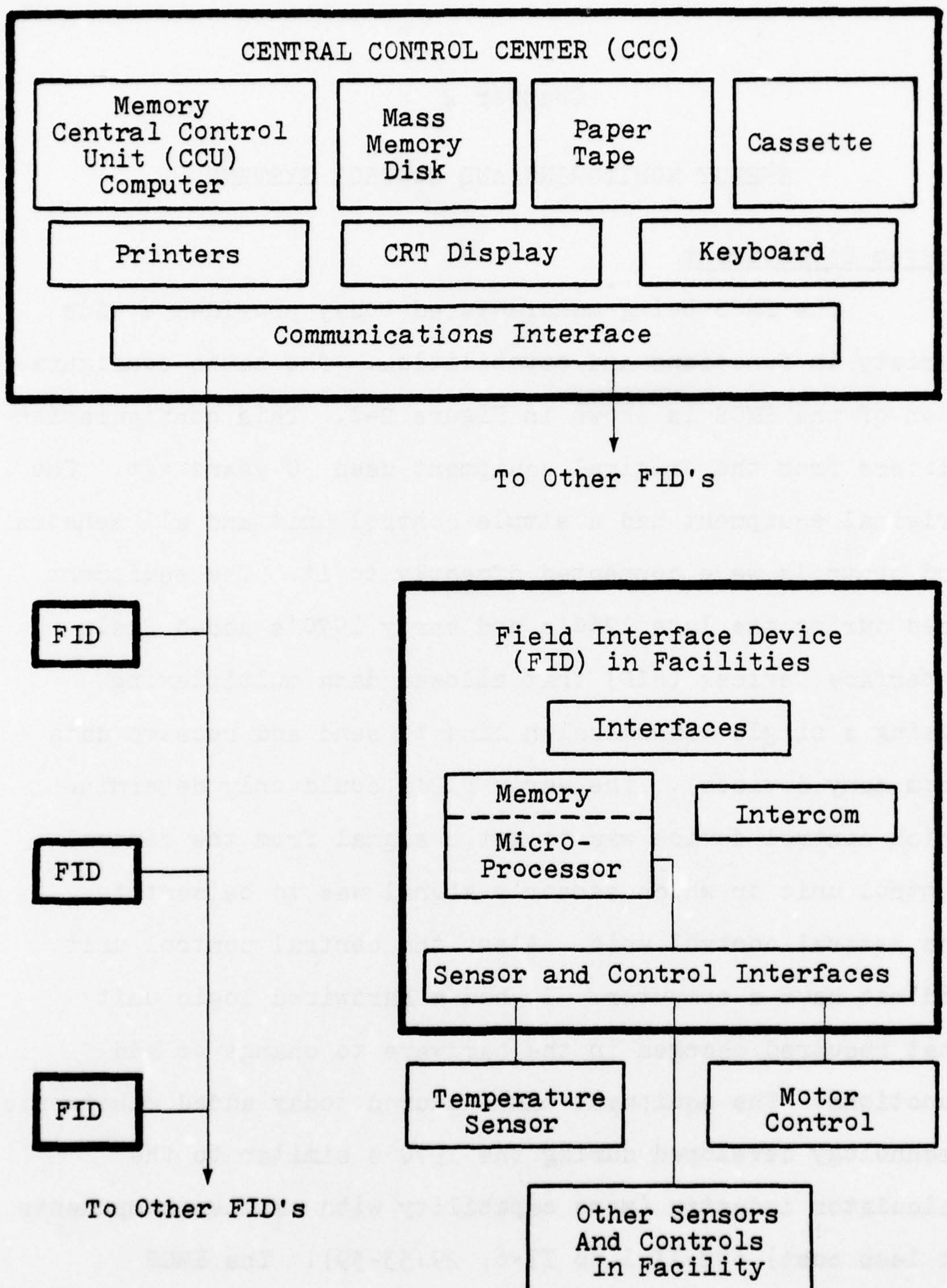


Figure 2-1 EMCS Configuration

System (EMCS) Applications Study" and the EMCS Guide Specifications Workgroup (32; 38).

EMCS Description

The EMCS (Figure 2-1) consists of a Central Control Center (CCC), a communications system, Field Interface Devices (FID), and local sensors and controls. The system operation is referred to as distributed processing because the FID performs many of the operations that would otherwise have to be accomplished at the CCC. These operations include receiving data from the local sensors, and performing calculations based on its stored memory and the data received. Therefore, much of the processing is distributed throughout the system (29:53-59).

The local controls and sensors may be the existing controls and sensors on the equipment or new controls and sensors. The sensors may be binary (sense two conditions such as on/off, flow/no flow, etc.) or they may be analog (sense rate, amount, etc.). The controls may also be binary or analog. Usually the controls are binary and use an analog sensor to determine when the control should be changed. An example is the use of an analog temperature sensor to turn a heater on and off by a binary control device. Analog control devices are also available such as a temperature control device with the set point controlled remotely. With this device the existing control circuits of the equipment are used to perform the actual operations

and the EMCS is used to determine the temperature setting. The only difference in the EMCS sensors and control devices from the existing ones is the signal sent to the FID.

The Field Interface Device consists of a microprocessor that controls its operation, some memory to store its operating programs and data, and various interface devices used to convert the various signals to a state which can be understood by the microprocessor and the devices connected to it. The distributed processing system uses the FID to work independently or together with the Central Control Center depending upon the situation. The FID will perform routine scanning to gather the sensor data and take action in response to this data. It will run routine programs such as starting and stopping equipment at predetermined times, and reporting problems and out-of-normal conditions (alarms). It essentially works on an exception basis. The FID also has the capability of changing its operation based on signals from the CCC. The changes may consist of different alarm limits to be used to determine when to send reports to the CCC, control commands to be issued by the FID based on data only available to the CCC, or changes in the program used by the FID.

The communications system is used to transfer information between the FID and CCC. It may consist of

telephone lines, twisted pairs of wires, coaxial cable, radio waves, microwave, or even the electrical distribution system. Each of the communication methods requires some sort of conversion device to condition or change the signals to the appropriate form for the method used.

The Central Control Center (CCC) is the last part of the system. The distributed processing system was developed to prevent the CCC from being the weak link in the system. The CCC consists of a Central Control Unit (CCU) or computer, CCU memory, mass memory storage, man-machine interface devices, and machine-machine interface devices. The man-machine interface devices consist of printers, Cathode Ray Tubes (CRT), keyboards, and various switches and display lights. These are used by the EMCS to tell the operator what is happening and by the operator to tell the EMCS what to do. The CCU memory is where the programs and data are stored that the CCU is currently using. The mass memory storage may consist of discs, tape, cassettes, or paper tape. The disc memory is usually available for the CCU to use at any time, while the other mass memory storage devices require operator intervention for the CCU to use them. Programs and data are stored on these devices.

The CCU operates in the same manner as the microprocessor in the FID. It determines what to do based on the various inputs, data, and programs. The main difference

between the operation of the CCU and the microprocessor is the more nonroutine nature of the CCU operation. It performs routine operations such as checking the operation of the FID's and communications system, gathering data from the FID's for the reports, and sending control signals for special operations (load shedding). However, it is usually waiting for inputs from the operator or reporting problems of a nonroutine nature. The programs in the CCU are designed to allow the operator to change the operation of the system by changing the alarm limits, changing the parameters used in optimization programs and start/stop programs, developing new programs for the operation of the FID's, and changing the existing programs.

EMCS Functions

The EMCS is designed to reduce life cycle costs and energy consumption. Its major functions include automatic start/stop of equipment, monitoring equipment operation, resetting and changeover of equipment, recording and logging equipment operations, alarm reporting, load shedding, and equipment optimization. The EMCS accomplishes these functions by using numerous sensors and controls connected to the facility equipment and a complex data processing system to determine the control commands to be issued. Each one of these functions will reduce life cycle costs and save energy (3:97-98; 38:12). The following description of the EMCS f[illegible]ctions was summarized from Bodak,

the Civil Engineering Center "Energy Monitoring and Control System (EMCS) Application Study," and the EMCS Guide Specifications Workgroup (3; 32; 38).

<u>Start/stop</u>. The automatic start/stop function allows the operator to select starting and stopping times for the equipment based on actual need for the equipment. Most of a facility's air handling equipment runs all of the time even though it may be needed only part of the time. By determining the actual times it is needed, the EMCS can be programmed to turn the equipment on and off. This function has advantages over time clocks because the time is taken from one central location and different settings can be made for different days and times during the day. Also, the manpower used to maintain the time clocks is eliminated with the EMCS.

<u>Monitoring</u>. Equipment operation monitoring can save manpower by allowing the operator to check the operation of equipment from one central location rather than sending personnel out to check the operation. Monitoring is also used to provide data for the other functions of the EMCS. Monitoring consists of sensing the operation of equipment by the use of thermostats, pressure sensors, flow sensors, relays, etc.

<u>Reset and changeover</u>. Resetting and changeover are used to change the operation of the equipment. Resetting

is used to change the operating points of equipment such as temperature, humidity, flow rate, etc. It saves energy by allowing the equipment to operate at efficient levels for all operating conditions. Changeover is used to change the operation from one system to another such as from heating to air conditioning. Currently, most Air Force bases change the operation at predetermined times during the year. This leads to uncomfortable conditions and wastes energy. It also takes a large number of manhours to perform the changeover manually.

Recording and logging. Manpower is saved by automatic recording and logging of conditions monitored by the EMCS. It also helps to determine if problems exist by providing a log of operating conditions that can be analyzed easily. Normally, it would take too much effort to obtain a log of operating conditions that are not necessary for reports but would be helpful in determining if problems exist in the operation.

Alarm reporting. An out-of-normal condition detected by the EMCS generates an alarm for the EMCS operator; the time, location, and problem are automatically recorded for permanent record. This function can save manpower, energy, and perhaps equipment by requiring immediate operator response to the undesired condition. For example, if a thermostat fails to work properly and allows the temperature in an unmanned warehouse to drop,

the material stored may be damaged. Also, the plumbing could be damaged. Another example is if the thermostat allowed the temperature to rise during the winter above normal conditions, energy would be wasted.

Load shedding. Load shedding is used to save electric costs by lowering the peak electric demand. It usually does not save much energy or manpower. However, it is easy to perform because the EMCS can use all equipment connected as start/stop points as load shedding points. This is accomplished by using sensors to determine the current electric demand and then predicting the future electric demand based on the rise in demand over time. If the predicted rise in demand exceeds a preset maximum demand the CCU will issue commands to stop equipment until the predicted demand is less than the preset maximum demand.

Equipment operation optimization. Optimization of equipment operation uses a combination of the other functions. It is used to determine the optimal start and stop times for the equipment. For example, the optimization programs can determine when to turn on heating equipment in the morning to have the building comfortable when the personnel arrive. It can also determine when to shut off the equipment in the afternoon in order to save energy and still provide comfort to the personnel

before they leave. While reset and changeover are usually performed by the operator of the EMCS, optimization programs determine the optimum set points and changeover times and automatically make the changes.

## Chapter 3

## METHODOLOGY

### Introduction

The methodology used to test the research hypotheses and answer the research question is presented in this chapter. A general summary of the methodology used for each hypothesis and the question is provided below.

Research hypothesis 1. (An EMCS can provide a payback of less than six years and an annual energy savings of at least 23 MBtu per $1000 invested.) First, the average payback and average energy saved per $1000 invested for the operational EMCS were calculated. Second, the average payback and average energy saved per $1000 invested were statistically tested against the hypothesized values of six years payback and 23 MBtu per $1000 invested to determine if they were statistically different from the hypothesized values. Finally, the results of the statistical tests were used in a criterion test to determine if the research hypothesis was true.

Research hypothesis 2. (The Architect-Engineer (A-E) feasibility studies accurately predict the energy saved, net operations and maintenance cost saved, and

EMCS initial cost per facility.) This hypothesis could not be tested by comparing the A-E feasibility studies directly against the operational data from EMCS approved based on feasibility studies because none of the systems designed from the studies was in operation long enough to provide data on the actual savings from the systems. Therefore, an indirect approach was used to compare the feasibility studies to the existing operational EMCS that were not approved with feasibility studies. First, Multiple Linear Regression (MLR) models were developed from the feasibility study data to predict the EMCS initial cost, net operations and maintenance cost saved, and energy saved. Independent variables used in the models were chosen based on the assumption that they were the ones that were related to the different dependent variables and explained the most variability in the dependent data values. Second, each model was tested to determine if it was statistically significant in explaining the variability in the data provided in the feasibility studies. Third, the independent variables were analyzed to determine if their effect on the dependent variables were as assumed. Fourth, the models were used to predict the EMCS initial cost, net operations and maintenance cost saved, and annual energy saved from operational EMCS that were not approved based on A-E feasibility studies. Fifth, confidence intervals about the predicted

values were developed and the operational EMCS cost and savings were tested to determine if the models were statistically significant in predicting the actual EMCS initial cost, net operations and maintenance cost saved, and energy saved. Finally, the results of the statistical tests were used in a criterion test to determine if the research hypothesis was true.

Research question. (Can Multiple Linear Regression (MLR) models be used to accurately predict the actual energy saved, net operations and maintenance cost saved, and EMCS initial cost per facility on an Air Force base?) First, MLR models were developed using the operational EMCS data to predict the energy saved, net operations and maintenance cost saved, and EMCS initial cost per facility. Second, each model was tested to determine if it was statistically significant in explaining the variability in the data. Third, the models were used to predict the EMCS initial cost, net operations and maintenance cost saved, and energy saved for the operational EMCS. Fourth, the actual operational EMCS cost and savings were statistically tested against the predicted values to determine if the predicted values were close enough to be of practical significance. Finally, the results of the statistical tests were used in a criterion test to determine how to answer the research question.

## Universe

The universe of interest in this research effort consisted of all Energy Monitoring and Control Systems designed for monitoring and controlling remote mechanical, electrical, utility, and life-safety building systems from a central location. This universe included EMCS designed for use anywhere, in either a single facility or in multiple facilities, and in different geographic locations throughout the United States. This universe included both public and private organizations.

## Population

The population of interest was limited to only those EMCS or portions of EMCS that were designed to reduce facility energy consumption and operations and maintenance costs. EMCS designed or used only to monitor facility operations were not included in this research effort. Also, EMCS designed specifically to reduce operations and maintenance costs for special operations not associated with the facility environmental systems, such as special hospital operations or laboratory experiments, were not included in this research effort.

## Sampling Plan

The sampling plan entailed gathering actual operating data and design data from EMCS meeting the population criteria. The required data consisted of EMCS

initial cost, energy saved, operations and maintenance cost saved, operations and maintenance cost for the EMCS, facility type, facility size, energy cost per unit for all types of energy, and heating and cooling degree days for each facility connected to the EMCS. The sampling plan for data from the operational EMCS consisted of attempting to get a census of the existing EMCS by telephone contacts with each major command EMCS project officer (1; 2; 4; 5; 8; 17; 19; 24; 26; 27; 40). However, a census was not obtained because of three factors. First, data were not being gathered for some of the systems. Second, some of the systems had only been in operation for a short period; therefore, data on the operation for all seasons were not available. Third, some of the data were collected on a base-wide basis and could not be attributed to specific facilities.

The sampling plan for data from the Architect-Engineer feasibility studies consisted of using feasibility studies from Air Force Logistics Command (AFLC) bases (5; 33; 34; 36; 42; 43). The AFLC bases were chosen as a representative sample for all Air Force installations in the United States for three reasons. First, the AFLC bases provide a wide variety of facilities both in size and function. Second, the AFLC bases are located throughout the United States with varied climate conditions and energy rates. Third, each feasibility study was accomplished by

a different Architect-Engineer firm and the A-E firms were selected by design agencies named by the Air Force. The same design agencies that selected the A-E firms for most of the AFLC EMCS projects also selected the A-E firms for most of the other Air Force EMCS projects. Thus, the studies developed for AFLC were considered a representative sample of Air Force EMCS feasibility studies.

## Data Base and Data Validity

The primary data used to test the hypotheses on operational EMCS were collected by the individual base personnel for each facility connected to the EMCS. The bases collected the data on the EMCS operation as a result of requests from their major commands or for their own use. General data on climate, facility type and size, and energy rates were requested for this research effort from the bases sampled. All of the data were existing and not created for this research effort. The data on EMCS cost and savings for each facility were considered valid because they are subject to audit by the General Accounting Office. Also, the data were considered valid because Headquarters Air Force, Engineering and Services has requested accurate operating data to present to Congress for the FY 79 Military Construction Program (MCP) hearings (13).

The data that were used to test the accuracy of the A-E feasibility studies were collected from the

feasibility studies sampled. The data on climate, energy rates, and facility type and size were collected from records at HQ AFLC Engineering and Services, Utilities Division. The data were considered valid because they were collected directly from the existing studies or records available at HQ AFLC Engineering and Services, Utilities Division.

Definition of Variables

Data elements that were collected for this research effort and other terms are defined for this research effort as follows:

Annual energy saved per \$1000 invested (MBtu/\$1000) (effectiveness). The total number of MBtu's saved per year in the facility divided by the cost in thousands of dollars to install the EMCS in the facility.

Degree days. The number of heating degree days for one day is the number of degrees Fahrenheit ($^{o}F$) the average temperature is below $65^{o}F$ for that day. If the average temperature is $65^{o}F$ or higher then the number of heating degree days is zero. The total number of heating degree days for one year is the sum of all the number of heating degree days for each day during the year. The number of cooling degree days for one day is the number of $^{o}F$ the average temperature is above $65^{o}F$ for that day. If the average temperature is $65^{o}F$ or lower then the number of

cooling degree days is zero. The total number of cooling degree days for one year is the sum of all the number of cooling degree days for each day during the year.

EMCS cost. The total construction cost applicable to each facility. In cases where a utility system or utility plant served many facilities included in the research effort, the cost attributable to the utility system or plant was allocated to the facilities based on the data analysis plan presented in the next section of this research effort.

Energy rate. The average cost per unit of energy for heating and electricity for FY 77. In cases where multiple fuels were used for heating, the average cost was calculated by converting all fuels used to MBtu and dividing the total cost by the total MBtu consumed.

Energy saved. The total amount of electricity, oil, gas, propane, or coal saved per year in the facility by the EMCS. Energy saved in utility systems or utility plants was allocated to the facilities based on the data analysis plan.

Facility. Any building in which electricity, heat energy, and cooling energy is used to light, heat, cool, or run equipment in the building. Buildings that serve a dual purpose of housing a utility plant and facility

operations are considered as two separate buildings unless the entire utility plant serves only the building in which it is installed. When the plant serves just the building it is located in, then the entire building is a facility.

Facility size. The total square footage of the facility under control of the EMCS. Where only an identifiable portion of the facility is under control of the EMCS, only that portion of the facility was used in determining the facility size.

Facility type. Two types of facilities were used. Laboratories are defined as any facility having strict environmental controls for the work in the facility. Laboratories included computer facilities, communications facilities, research laboratories, and electronic repair facilities. All other facilities constitute the second category of facility type.

Net operations and maintenance (O&M) cost saved. The total cost of energy saved per year, manhours cost saved per year, and O&M materials and supplies cost saved per year minus the O&M cost per year for the EMCS attributable to the facility. The allocation of O&M costs to each facility was based on the data analysis plan.

Payback (efficiency). The number of years required for the sum of the annual net O&M savings of a facility to equal the EMCS cost for that facility.

Utility systems/plants. A utility system or utility plant is any system or plant used to produce or transport electricity, heat energy, cooling energy, or water to the facilities using the energy or water. A utility system or utility plant is also a system or plant for transporting or processing waste products from the facilities. Buildings used to produce, transport or convert energy from one form to another, such as from electricity to cooling energy, for use primarily in other buildings are utility systems or utility plants.

## Data Analysis

The data analysis portion of the research effort utilized the data collected as described above. The process consisted of three stages; purging the sample, preparation of the sample, and operating on the data. A description of each stage follows:

Purging the sample. The data collected from both the operational EMCS and feasibility studies were reviewed for each facility and utility system/plant. The following data were purged during this stage in order to eliminate data not in the population desired:

1. All of the data for facilities or utility systems/plants that had only monitoring functions performed in the facilities or utility systems/plants.

2. All of the data for utility systems/plants where the data could not be allocated to the facilities served by the utility systems/plants based on the size of the facilities served or the number of sensors and controls in the facilities served by the utility systems/plants.

3. All of the data for facilities or utility systems/plants in which data for all of the variables could not be obtained.

Preparation of the sample. The data left after the purging stage were then converted to common terms. All cost figures were converted to thousands of dollars, square footage values were converted to thousands of square feet, and degree days were converted to thousands of degree days.

Next, the data for the utility systems/plants were distributed to the facilities connected to the utility systems/plants in order to get the population desired (EMCS initial cost, net O&M cost saved and energy saved per facility). The EMCS initial cost, net operations and maintenance cost saved, and energy saved were distributed based on the facility size. The total square feet of all facilities connected to the utility system/plant was determined. This ratio for each facility was used to allocate the EMCS

initial cost, net O&M cost saved, and energy saved to each facility.

Finally, the EMCS operations and maintenance cost increase due to the EMCS and the Central Control Center and communications system initial costs were allocated to each facility. The EMCS operations and maintenance cost was allocated to each facility based on the ratio of the EMCS initial cost of each facility to the total EMCS initial cost of all facilities. The Central Control Center and communications system initial costs were allocated to each facility based on the ratio of sensors and controls in each facility to the total number of sensors and controls in all facilities. The number of sensors and controls was used in this calculation because the Central Control Center and communications system cost is related to the number of sensors and controls (32; 38).

Operating on the data. Operating on the data consisted of performing mathematical calculations on the data to get the data in the form required for the statistical tests described in the next section. The first operation consisted of calculating the average annual payback and standard deviation of the payback for the operational facilities. This was accomplished by the following steps:

1. The payback for each facility was calculated by using the following formula:

$$\text{Payback (years)} = N_i =$$

$$\frac{\text{Initial cost (\$1000)}}{[\text{Energy saved (\$1000)}](1+I)^{N_i} - [\text{Net O\&M cost (\$1000)}](1+I)^{N_i}}$$

$N_i$ = Payback (years) for facility i

I = Escalation factor (Appendix B contains a description of the escalation factors used in the calculations and a detailed description of the procedure used).

2. The average annual payback ($\overline{X}_a$) was then calculated using the following formula (25:48):

$$\overline{X}_a = \frac{\sum_{i=1}^{n} f_i N_i}{\sum_{i=1}^{n} f_i} = \text{average annual payback}$$

$$f_i = \frac{\text{Initial cost (\$000) facility i}}{\text{Initial cost (\$000) all facilities}}$$

n = number of facilities in the sample

3. Finally, the standard deviation of the payback ($s_a$) was calculated using the following formula (25:48):

$$s_a = \sqrt{\frac{\sum_{i=1}^{n} f_i N_i^2 - \frac{\left(\sum_{i=1}^{n} f_i N_i\right)^2}{\sum_{i=1}^{n} f_i}}{\sum_{i=1}^{n} f_i}} = \text{standard deviation}$$

The second operation consisted of calculating the average annual energy saved per $1000 invested and the standard deviation of the energy saved per $1000 invested for the operational facilities. This was accomplished by the following steps:

1. The energy saved per $1000 invested ($M_i$) was calculated for each facility by using the following formula:

$$M_i = \frac{\text{Total MBtu saved in facility i}}{\text{Initial cost in facility i}}$$

2. The average energy saved per $1000 invested ($\overline{X}_b$) was then calculated using the following formula (25:33):

$$\overline{X}_b = \frac{\sum_{i=1}^{n} M_i}{n}$$

3. Finally, the standard deviation of the energy saved per $1000 invested ($s_b$) was calculated using the following formula (25:248):

$$s_b = \sqrt{\frac{\sum_{i=1}^{n} (M_i - \overline{X}_b)^2}{n-1}}$$

The third operation consisted of using the feasibility study data to develop Multiple Linear Regression (MLR) models of the EMCS initial cost, net O&M cost saved, and annual energy saved. Multiple Linear Regression was chosen because it is a "technique used to predict the value of one quantitative variable by using its relationship with one or more additional quantitative variables [25:391]." The MLR model used was of the following form:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_1x_5$$

Three models of this form were developed, one for each of the dependent variables desired (EMCS initial cost, net O&M cost saved, and energy saved). In each model, y is the dependent variable; $x_1$, $x_2$, $x_3$, and $x_4$ are the ratio level independent variables; $x_5$ is the nominal level categorical variable; and $x_1x_5$ is an interaction variable. The term $b_0$ is a constant. The terms $b_1$, $b_2$, $b_3$, and $b_4$ are

the net regression coefficients and each represents the change in y per unit change in the corresponding independent variable. The term $b_5$ is a regression coefficient that represents a change in the dependent variable caused by different facility types. The term $b_6$ is a net regression coefficient that represents the change in y because of the interaction between independent variables $x_1$ and $x_5$ (16; 21; 22; 25). A more complete description of Multiple Linear Regression is contained in Appendix C. Table 3-1 shows what each independent variable represents.

TABLE 3-1

MLR Independent Variables

| Independent Variable | Level | Description |
|---|---|---|
| $x_1$ | ratio | square feet (000) |
| $x_2$ | ratio | electric rate ($/MWH[1]) |
| $x_3$ | ratio | heat energy rate ($/MBtu) |
| $x_4$ | ratio | heating & cooling degree days |
| $x_5$ | nominal (0 or 1) | 0 - all other facilities<br>1 - laboratories, hospitals, and 24 hour/day operated facilities |

These variables were used because it was easy to obtain data for them and they should be related to the

[1]MWH: Megawatt-hour

dependent variables. Variable $x_1$, the size of the facility, should be directly related to the EMCS initial cost, net O&M cost saved, and energy saved. Variables $x_2$ and $x_3$, energy rates, should be directly related to the net O&M cost saved and could influence the EMCS initial cost and energy saved. Variable $x_4$, degree days, should be directly related to the energy saved. Variable $x_5$ and the interaction variable $x_1x_5$ should be directly related to the EMCS initial cost, net O&M cost saved, and energy saved and show that the different types of facilities cost different amounts to install the EMCS and save different amounts of money and energy.

In order to determine if these relationships were true, the correlation coefficients ($r_{x_jy}$) between each independent variable ($x_j$, j = 1, ..., 6) and the dependent variable (y) for each model were determined as follows (16:43):

$$r_{x_jy} = \frac{\dfrac{\sum_{i=1}^{n} (x_{ij}-\bar{X}_j)(y_i-\bar{Y})}{n-1}}{\sqrt{\dfrac{\sum_{i=1}^{n} (x_{ij}-\bar{X}_j)^2}{n-1}}\sqrt{\dfrac{\sum_{i=1}^{n} (y_i-\bar{Y})^2}{n-1}}}$$

$$\bar{X}_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \qquad \bar{Y} = \frac{\sum_{i=1}^{n} y_i}{n}$$

The models were built and the correlation coefficients determined using the Statistical Package of the Social Science (SPSS) computer program on the CREATE computer system (22:320-367).

The fourth operation on the data consisted of developing confidence intervals (25:541-544) about the regression hyperplanes using the operational facilities independent variable data values and determining the percentage of operational EMCS dependent variable values that fell within these confidence intervals. This was accomplished by the following steps:

1. Confidence intervals for each operational facility were calculated using the following formula (21:208-230):

$$\text{upper limit} = y(\text{next}) + (t_{\alpha/2,n-p})s(y(\text{next}))$$

$$\text{lower limit} = y(\text{next}) - (t_{\alpha/2,n-p})s(y(\text{next}))$$

y(next) = predicted value of the dependent variable value using the MLR model.

$t_{\alpha/2,n-p}$ = students-t distribution value (the selection of the parameters $\alpha$, n, and p are discussed in the next section)

s(y(next)) = standard deviation of y(next)

A computer program was developed to determine the confidence intervals and is listed in Appendix D. Also, a more complete discussion of confidence intervals is included in Appendix E.

2. The operational EMCS dependent variable data values for each facility in each model were checked against the confidence intervals to determine how many actually fell within the confidence intervals.

3. Finally, the percentage of operational data dependent variable values that fell within the confidence intervals was determined for each model (EMCS initial cost, net O&M cost saved, and energy saved).

The fifth operation on the data consisted of developing MLR models using the operational EMCS data values. The models were of the same form used in the third operation:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_1x_5$$

Three models were developed, one for each of the dependent variables desired (EMCS initial cost, net operations and maintenance cost saved, and energy saved). Next, the models were used to predict the operational EMCS dependent variable data values. Finally, the percentage of operational EMCS dependent variable data values that fell

within plus or minus 20 percent of the prediction values was determined for each model.

## Statistical and Criterion Tests

In order to accept or reject the research hypotheses and answer the research question, the research hypotheses and research question were broken down into basic parts that could be statistically tested. Then, the results of the statistical tests were used in criterion tests to accept or reject the research hypotheses and answer the research question. The statistical tests were made at $\alpha = .10$ level of significance, 90 percent confidence in the results.

The basic form of the statistical test consisted of testing a hypothesis of the following type:

$$H_0: \theta \; ( \leq, =, \geq ) \; \theta_0$$

$$H_a: \theta \; ( >, =, < ) \; \theta_0$$

$H_0$ represents the null hypothesis and $H_a$ the alternate hypothesis. $\theta_0$ is the hypothesized value of the population parameter, $\theta$, to be tested. The statistical test is made to determine if the null hypothesis, $H_0$, is rejected or not rejected at an alpha, $\alpha$, level of significance. Alpha, $\alpha$, represents the probability of making a Type I error, rejecting a null hypothesis when it is true (25:275-277). Picking an appropriate error probability, $\alpha$, is a judge-

mental decision on the part of the researchers (28:167-168). However, as the alpha level is decreased (higher confidence in the results) the probability of making a Type II error increases, not rejecting a null hypothesis when it is false (25:277).

The hypothesis is set up with what is desired to be proved in the alternate hypothesis; because if $H_o$ is rejected, we are sure that a wrong decision (Type I error) is at most $\alpha$ (25:275,302). For example, if we want to prove that the average age of military personnel is greater than 25 years with 95 percent confidence ($\alpha = .05$), we would use the following hypothesis:

$$H_o: \; U \leq 25$$

$$H_a: \; U > 25$$

where U represents the population parameter, average age of military personnel. If $H_o$ is rejected at $\alpha = .05$ level of significance, we could conclude that the average age of military personnel is greater than 25 years with 95 percent confidence. However, if $H_o$ is not rejected, we could not conclude that the average age of military personnel is less than 25 years with 95 percent confidence because now we have possibly committed a Type II error, not rejecting $H_o$ when it is false. Determining the probability of committing a Type II error requires the actual value of

the population parameter, $\theta$, which is usually not known (25:278-298).

Each of the criterion tests is presented below, followed by the statistical tests. An additional statistical test was used while developing the MLR models for research hypothesis 2 to determine if the independent variable used in the models affected the dependent variables as expected. This statistical test was not used in the criterion test for the second research hypothesis.

Criterion test 1. The first criterion test is to accept research hypothesis 1, that the average payback is less than six years and the average annual energy saved per $1000 invested is greater than 23 MBtu per $1000 invested, if $H_{oa}$ and $H_{ob}$ are both rejected. The statistical tests used were as follows:

1. The statistical test used on the payback data consisted of testing the following hypothesis:

$$H_{oa}: U_a \geq 6 \text{ years}$$

$$H_{aa}: U_a < 6 \text{ years}$$

where $U_a$ is the population parameter, average payback period. With this test, $H_{oa}$ was rejected if (25:315):

$$\frac{\overline{X}_a - 6}{s_a/\sqrt{n}} < -t_{\alpha, n-1}$$

Where $t_{\alpha, n-1}$ represents the value of the student's t-distribution at $\alpha$ level of significance and n-1 degrees of freedom and n represents the number of operational facilities used to compute $\overline{X}_a$ and $s_a$.

2. The statistical test used on the annual energy saved per $1000 invested consisted of testing the following hypothesis:

$$H_{ob}: \; U_b \leq 23 \text{ MBtu/\$1000 invested}$$

$$H_{ab}: \; U_b > 23 \text{ MBtu/\$1000 invested}$$

where $U_b$ is the population parameter, average annual energy saved per $1000 invested. With this test, $H_{ob}$ was rejected if (25:315):

$$\frac{\overline{X}_b - 23}{s_b/\sqrt{n}} > t_{\alpha, n-1}$$

where $t_{\alpha, n-1}$ is the same value used in the previous test.

Criterion test 2. The second criterion test is to accept research hypothesis 2, that the A-E feasibility studies accurately predict the actual energy saved, net

operations and maintenance cost saved, and EMCS initial cost per facility, if $H_{oc}$ and $H_{oe}$ are rejected for each model. The statistical tests used were as follows:

1. The following hypothesis for each of the three feasibility study MLR models was tested:

$$H_{oc_i}: \quad R^2 = 0$$

$$H_{ac_i}: \quad R^2 \neq 0$$

$$i = 1, 2, 3 \text{ (each model)}$$

where $R^2$ represents the coefficient of determination for each model (Appendix C). With this test, $H_{oc_i}$ was rejected for each model if (16:54-93):

$$\frac{MSR}{MSE} = \frac{\text{Mean Square Regression}}{\text{Mean Square Error}} > F_{\alpha, p-1, n-p}$$

where $F_{\alpha, p-1, n-p}$ represents the F-distribution with level of significance $\alpha$, MSR degrees of freedom p-1, and MSE degrees of freedom n-p (25:549). The value p is the number of independent variables plus one and n is the number of facilities used in constructing the models.

2. The statistical test used on the correlation coefficients to determine how the independent variables affected each dependent variable consisted of testing the

following hypothesis for each correlation coefficient:

$$H_{od_{(i,j)}}: \rho_{x_i y_j} = 0$$

$$H_{ad_{(i,j)}}: \rho_{x_i y_j} \neq 0$$

i = 1, 2, 3 (each model)

j = 1, ..., 6; subscript 6 represents the variable $x_1x_5$ (each variable)

where $\rho_{x_i y_j}$ represents the correlation coefficient between independent variable i and dependent variable j. With this test, $H_{od_{(i,j)}}$ was rejected for each variable if (16:49):

$$\left| \frac{r_{x_i y_j}\sqrt{n-2}}{\sqrt{1-r^2_{x_i y_j}}} \right| > t_{\alpha/2,n-2}$$

3. The statistical test used on the confidence intervals consisted of testing the following hypothesis for each model:

$$H_{oe_i}: \% \leq 90\%$$

$$H_{ae_i}: \% > 90\%$$

i = 1, 2, 3 (each model)

where % represents the percentage of operational EMCS dependent variable data values that are within the 90 percent confidence intervals about the predicted dependent variable data values. With this test, $H_{oe}$ was rejected for each model if the percentage of operational facilities dependent variable data values that fell within the confidence intervals was greater than 90 percent. Ninety percent was used because the confidence intervals were constructed with $\alpha$ = .10 or 90 percent confidence.

Criterion test 3. The third criterion test is to answer yes to the research question, that MLR models can be used to accurately predict EMCS initial cost, net operations and maintenance cost saved, and energy saved, if $H_{of}$ and $H_{og}$ are rejected for each model. The statistical tests used were as follows:

1. The statistical test used on the operational EMCS models consisted of testing the following hypothesis for each model:

$$H_{of_i}: \quad R^2 = 0$$

$$H_{af_i}: \quad R^2 \neq 0$$

$$i = 1,\ 2,\ 3 \text{ (each model)}$$

where $R^2$ represents the coefficient of determination for each model (Appendix C). With this test, $H_{of_i}$ was rejected

for each model if (16:54-93):

$$\frac{MSR}{MSE} = \frac{\text{Mean Square Regression}}{\text{Mean Square Error}} > F_{\alpha, p-1, n-p}$$

where $F_{\alpha, p-1, n-p}$ represents the F-distribution value with level of significance $\alpha$, MSR degrees of freedom p-1, and MSE degrees of freedom n-p (25:549).

2. The statistical test used on the percentage of operational facilities dependent variable data values that fell within plus or minus 20 percent of the predicted values consisted of testing the following hypothesis for each model:

$$H_{og_i}: \% \leq 90\%$$

$$H_{ag_i}: \% > 90\%$$

$$i = 1, 2, 3 \text{ (each model)}$$

where % represents the percentage of actual data values that fell within plus or minus 20 percent of the predicted values. With this test, $H_{og}$ was rejected for each model if the actual percentage of operational facilities dependent variable data values that fell within plus or minus 20 percent of the predicted values was greater than 90 percent. Ninety percent was used to be at least 90 percent confident in the result.

Assumptions

In order to perform the statistical tests the following assumptions were made:

1. The population of operational EMCS annual payback and energy saved per $1000 invested are normally distributed.

2. The error terms $e_i$ associated with the MLR models exhibit the following properties (16:89):

(a) $e_i$ and $e_j$ are uncorrelated for all $i \neq j$.

(b) The expected value of the error terms, $E(e_i)$, is zero.

(c) The variance of the error terms, $V(e_i)$, is constant for all i.

(d) The error terms are normally distributed: $e_i \cap N(0, \sigma^2)$.

(e) The sample observations of the independent variables are linearly independent.

The following general assumptions were made:

1. Other independent variables such as age of facilities, construction of the facilities, type of heating system, etc., will not change the results of the statistical tests.

2. All data received were collected and reported accurately.

Limitations

The results can only be generalized to the population described. Any generalization to the universe can only be made by logical inference.

The technology in the EMCS field is rapidly changing, which limits generalization to EMCS that are already designed or started construction. Generalizations to future EMCS applications can only be made by logical inferences.

# Chapter 4

# DATA ANALYSIS

## Introduction

In this chapter the results of the operation on the data and statistical tests are presented. The analysis to support the two research hypotheses and the research question are presented in separate sections to provide a correlation between the data operations, tests, hypotheses, and question. The beginning of each section contains a restatement of the research hypothesis or research question presented in chapter 1 to provide an easy reference for the reader.

## Research Hypotheses 1

The research hypothesis was: An EMCS can provide a payback of less than six years and an energy savings of at least 23 MBtu per $1000 invested.

A summary of the results of the operations on the data and the statistical tests are presented below:

1. Average payback (the payback per facility is presented in Appendix B):

$$\bar{X}_a = 4.60 \text{ years}$$

$$s_a = 4.467 \text{ years}$$

$$n = 30$$

$$\frac{\bar{X}_a - 6}{s_a/\sqrt{n}} = -1.717 < -1.312 = -t_{\alpha/2,n-1}$$

Therefore, reject $H_{oa}$ and accept $H_{aa}$, the average payback is less than six years at $\alpha$ = .10 level of significance.

2. Average annual energy saved per $1000 invested (annual energy saved per $1000 invested per facility is in Appendix B).

$$\bar{X}_b = 160.3 \text{ MBtu}$$

$$s_b = 13.8 \text{ MBtu}$$

$$n = 30$$

$$\frac{\bar{X}_b - 23}{s_b/\sqrt{n}} = 54.5 > 1.312 = t_{\alpha/2,n-1}$$

Therefore, reject $H_{ob}$ and accept $H_{ab}$, the average annual energy saved per $1000 invested is greater than 23 MBtu at $\alpha$ = .10 level of significance.

Research Hypothesis 2

The research hypothesis was: The A-E feasibility studies accurately predict the actual energy saved, net operations and maintenance cost saved, and EMCS initial cost per facility.

Three models were constructed as specified in Chapter 3 and are presented in Table 4-1. A summary of the statistical test performed on each of the models is presented below:

1. EMCS initial cost.

$$R^2 = .791$$

$$\frac{MSR}{MSE} = \frac{133,843.8}{5,744.82} = 23.30 > 1.94 = F_{\alpha, p-1n-p}$$

$$p = 7$$

$$n = 44$$

Therefore, reject $H_{oc_1}$ and accept $H_{ac_1}$, $R^2 \neq 0$ at $\alpha = .10$ level of significance.

2. Net O&M cost saved.

$$R^2 = .755$$

$$\frac{MSR}{MSE} = \frac{25,863.72}{1,359.73} = 19.02 > 1.94 = F_{\alpha, p-1, n-p}$$

Therefore, reject $H_{oc_2}$ and accept $H_{ac_2}$, $R^2 \neq 0$ at $\alpha = .10$ level of significance.

3. Energy saved.

$$R^2 = .736$$

$$\frac{MSR}{MSE} = \frac{1,537.51}{89.60} = 17.16 > 1.94 = F_{\alpha, p-1, n-p}$$

TABLE 4-1

EMCS Feasibility Study Models

$$\text{EMCS initial cost (\$000)} = -305.22325 + .257x_1 - .25233x_2 + 126.92256x_3 + 30.90572x_4 - 60.71189x_5 + .55699x_1x_5$$

$$\text{Net O\&M cost saved (\$000)} = -325.80725 + .00633x_1 + 1.18366x_2 + 90.47906x_3 + 33.99106x_4 - 31.01828x_5 + .30047x_1x_5$$

$$\text{Energy saved (000 MBtu)} = -89.48948 + .01912x_1 + .28219x_2 + 19.09615x_3 + 11.38993x_4 - .185084x_5 + .04112x_1x_5$$

$x_1$ = (000) square feet

$x_2$ = \$/MWH (electric rate)

$x_3$ = \$/MBtu (heat rate)

$x_4$ = (000) heating & cooling degree days

$x_5$ = { 1 - laboratories, hospitals, communication facilities, and facilities repairing electronic equipment
0 - all other facilities

Therefore, reject $H_{oc_3}$ and accept $H_{ac_3}$, $R^2 \neq 0$ at $\alpha = .10$ level of significance.

The correlation coefficients for each of the variables were developed as described in Chapter 3 and are presented in Table 4-2.

The test statistics for each correlation coefficient were determined and are presented in Table 4-3 with the results of the statistical tests. A complete listing of the SPSS results for the MLR models and correlation coefficients is contained in Appendix F.

The percentage of operational facility data values that fell within the confidence intervals were as follows (Appendix G contains a complete listing of the confidence intervals):

EMCS initial cost = 100 %

Net O&M cost saved = 100 %

Energy saved = 96.7%

Therefore, reject $H_{oe}$ and accept $H_{ae}$ for each model, the percentage of operational facilities dependent data values that fell within the confidence intervals exceeded 90 percent at $\alpha = .10$ level of significance.

## Research Question

The research question was: Can Multiple Linear Regression (MLR) models be used to accurately predict the actual energy savings, net operations and maintenance

TABLE 4-2

Correlation Coefficients

| Independent Variable | Dependent Variable | | |
|---|---|---|---|
| | $Y_1$ = Initial Cost | $Y_2$ = Net O&M Cost | $Y_3$ = Energy Saved |
| $x_1$ | .803 | .676 | .640 |
| $x_2$ | .006 | - .020 | - .241 |
| $x_3$ | .303 | .356 | .121 |
| $x_4$ | .050 | .148 | .455 |
| $x_5$ | .243 | .298 | .459 |
| $x_1x_5$ | .799 | .730 | .662 |

TABLE 4-3

Correlation Coefficients Test Statistics

| Independent Variable | Model | | | | | |
|---|---|---|---|---|---|---|
| | Initial Cost | | Net O&M Cost Saved | | Energy Saved | |
| $x_1$ | 8.73 | Y | 5.96 | Y | 5.40 | Y |
| $x_2$ | .04 | N | .13 | N | 1.61 | N |
| $x_3$ | 2.06 | Y | 2.47 | Y | .79 | N |
| $x_4$ | .32 | N | .97 | N | 3.31 | Y |
| $x_5$ | 1.62 | N | 2.02 | Y | 3.35 | Y |
| $x_1x_5$ | 8.61 | Y | 6.92 | Y | 5.72 | Y |

$t_{\alpha/2,n-2} = t_{.10/2,42} = 1.682$

Y = $H_{od_j}$ rejected and $H_{ad_j}$, $\rho_{x_i y_j} \neq 0$, accepted at $\alpha$ = .10 level of significance.

N = $H_{od_j}$ not rejected at $\alpha$ = .10 level of significance.

cost savings, and EMCS initial cost per facility on an Air Force base?

Three models were constructed as specified in Chapter 3 and are presented in Table 4-4. A summary of the statistical tests performed on each of the models is presented below (a complete listing of the SPSS results for these models is contained in Appendix H):

1. EMCS initial cost.

$$R^2 = .707$$

$$\frac{MSR}{MSE} = \frac{4371.39}{472.16} = 9.258 > 2.047 = F_{\alpha,p-1,n-p}$$

$$\alpha = .10$$
$$n = 30$$
$$p = 7$$

Therefore, reject $H_{of_1}$ and accept $H_{af_1}$, $R^2 \neq 0$ at $\alpha = .10$ level of significance.

2. Net operations and maintenance cost saved.

$$R^2 = .866$$

$$\frac{MSR}{MSE} = \frac{1828.23}{73.51} = 24.871 > 2.047 = F_{\alpha,p-1,n-p}$$

Therefore, reject $H_{of_2}$ and accept $H_{af_2}$, $R^2 \neq 0$ at $\alpha = .10$ level of significance.

TABLE 4-4

Operational EMCS Models

$$\text{EMCS initial cost (\$000)} = -81.94375 + .63259x_1 + 24.35387x_2 - 171.62652x_3 - 54.97288x_4 + 34.26759x_5 - .46877x_1x_5$$

$$\text{Net O\&M cost saved (\$000)} = 47.76679 + .13584x_1 - .71295x_2 - .58217x_3 - 5.81185x_4 + .30394x_5 + .12556x_1x_5$$

$$\text{Energy saved (000 MBtu)} = 78.18141 + .06075x_1 - 2.46052x_3 + .86336x_3 - 3.38622x_4 - .02049x_5 + .05799x_1x_5$$

$x_1$ = (000) square feet

$x_2$ = \$/MWH (electric rate)

$x_3$ = \$/MBtu (heat rate)

$x_4$ = (000) heating & cooling degree days

$$x_5 = \begin{cases} 1 - \text{laboratories, hospitals, communications facilities, computer facilities, and facilities repairing electronic equipment} \\ 0 - \text{all other facilities} \end{cases}$$

3. Energy saved.

$$R^2 = .855$$

$$\frac{MSR}{MSE} = \frac{566.08}{24.954} = 22.685 > 2.047 = F_{\alpha, p-1, n-p}$$

Therefore, reject $H_{of_3}$ and accept $H_{af_3}$, $R^2 \neq 0$ at $\alpha = .10$ level of significance.

The percentage of operational EMCS data values that fell within plus or minus 20 percent of the predicted values were as follows (a listing of all the actual values and predictions is presented in Appendix I):

EMCS initial cost = 36.7%

Net O&M cost saved = 13.3%

Energy saved = 16.7%

Therefore, do not reject $H_{og}$ for each of the models at $\alpha = .10$ level of significance.

# Chapter 5

# CONCLUSIONS

## Introduction

In this chapter the results of the criterion tests are presented with a discussion of the results. Each criterion test is presented in a separate section to provide a correlation between the criterion tests and research hypotheses. Each of the criterion tests is repeated for easier reference at the beginning of each section.

## Criterion Test 1

The first criterion test was to accept research hypothesis 1, that the average payback is less than six years and the average annual energy saved per $1000 invested is greater than 23 MBtu/$1000 invested, if $H_{oa}$ and $H_{ob}$ are both rejected. $H_{oa}$ and $H_{ob}$ were both rejected in Chapter 4; therefore, accept research hypothesis 1. Current EMCS provide an average payback of less than six years (4.6 years) and an average energy saved per $1000 invested of greater than 23 MBtu per $1000 invested (160 MBtu/$1000).

This result is extremely encouraging because the operational EMCS used in the analysis were designed and

approved for installation prior to the issuance of the current criteria (6; 14; 38). Also, some of these systems experienced the problems described in Chapter 1: Unexperienced designers, bad cost estimates, unreliable equipment, and outmoded technology (38). Because of the large average energy saved per $1000 invested (160.3 MBtu/$1000) and low average payback (4.6 years) obtained for these early EMCS, it can be logically included that future EMCS should be able to exceed the criteria for the following reasons:

1. Increased technology should reduce the initial cost or rate of increase in initial cost in comparison to increases in energy and O&M costs.

2. Increased knowledge in the proper design and installation of an EMCS should eliminate unnecessary sensors and controls that increase the initial cost but do not contribute to the savings.

3. More use of energy conservation techniques, such as optimization of equipment, that were not available on the early EMCS installed in the Air Force should increase the O&M cost saved and energy saved.

4. More competition in manufacturing and installing the systems should reduce the initial, the operation, and the maintenance costs of the system.

The alpha level ($\alpha$) chosen of .10 could have been decreased to .05 to have 95 percent confidence in the hypothesis with the same results. Therefore, it can be

concluded with 95 percent confidence that the operational EMCS have a payback of less than six years and an energy savings of greater than 23 MBtu per $1000 invested.

<u>Criterion Test 2</u>

The second criterion test was to accept research hypothesis 2, that the Architect-Engineer (A-E) feasibility studies accurately predict the actual EMCS initial cost, net operations and maintenance cost saved, and energy saved per facility, if $H_{oc}$ and $H_{oe}$ are rejected for each model. $H_{oc}$ and $H_{oe}$ were both rejected for each model in Chapter 4; therefore, accept research hypothesis 2. It can be concluded that the A-E firms are accurately predicting the EMCS cost and savings.

This result shows that either the doubts expressed by the Air Force engineers (38) were incorrect or the A-E firms improved their estimating techniques in the studies used for this research effort. The later appears to be the actual situation because the A-E feasibility studies used were performed after the doubts were expressed. This allowed the A-E firms time to gain more experience after they heard that the Air Force was unsatisfied with past performance on EMCS designs. Therefore, it can be logically concluded that as the A-E firms continue to gain experience they should become even more accurate in their estimates.

The results of the statistical tests on the correlation coefficients showed that: (1) The size of the facility is directly related to the EMCS initial cost, net O&M cost saved, and energy saved. (2) The heating rate is directly related to the net O&M cost saved but the electric rate is not significantly related to the net O&M cost saved. (3) The amount of degree days is directly related to the amount of energy saved. (4) The type of facility is directly related to the net O&M cost saved and energy saved but is not significantly related to the EMCS initial cost. (5) The interaction variable $x_1x_5$ is directly related to the EMCS initial cost, net O&M cost saved, and energy saved.

The only significant departure from the assumptions in Chapter 4 was that the electric rate was not significantly related to the net O&M cost saved. This result probably occurred because the net O&M cost saved depended more on the type and size of the facility than the electric rate as evident in the high correlation coefficients for the size of a facility ($r = .676$) and the interaction between the type and size of the facility ($r = .730$). Therefore, what the facility is used for and how big it is contributes more to the net O&M cost savings than the electric rate.

From Table 4-2, it can be concluded that the size of the facility and the interaction between the type and

size of the facility are more significantly related to the EMCS initial cost, net operations and maintenance cost saved, and energy saved than any of the other variables. Also, in determining the energy saved in a facility, the type of facility and number of degree days contribute a significant amount of information. Therefore, the heating and electric rates at a particular base should not be considered too heavily when determining whether an energy monitoring and control system should be installed in a particular facility.

Criterion Test 3

The third criterion test was to answer yes to the research question, that MLR models can be used to accurately predict EMCS initial cost, net operations and maintenance cost saved, and energy saved, if $H_{of}$ and $H_{og}$ are rejected for each model. $H_{of}$ was rejected for each model but $H_{og}$ was not rejected for each model in Chapter 4; therefore, do not answer yes to the research question. It can be concluded that Multiple Linear Regression models with the variables chosen cannot be used to accurately predict the cost and savings from an EMCS.

This result implies that the assumption made in Chapter 3, that other independent variables such as age of the facilities, type of equipment in the facilities, etc., would not affect the statistical tests is false for building accurate MLR models. The EMCS initial cost model

was the most accurate with 36.7 percent of the actual values within plus or minus 20 percent of the predicted values. Additional variables that could be included in this model to improve its predictive capability are the number of sensors and controls, type of sensors and controls, type of communications system, number of field interface devices, number of different functions performed in the facility, and accessibility of equipment to install the sensors and controls. Since these additional variables would require a detailed study of each facility, similiar to the current estimating techniques, a model would not provide an easier way to estimate the EMCS initial cost. Therefore, the current estimating techniques involving extensive facility surveys are an accurate and desirable way to estimate the EMCS initial cost.

The net operations and maintenance cost saved model was the least accurate with only 13.3 percent of the actual values within plus or minus 20 percent of the predicted values. Additional variables that could be included in the model to improve its predictive capability include the number and size of motors controlled, the hours of operation required for each motor, the number and size of heating units, the type of functions performed on each piece of equipment (start-stop, optimization, load shedding, etc.), number and type of sensors and controls, age of the facility, and type of construction. Again, gathering this type of

information requires a detailed study of each facility similar to the A-E feasibility studies and a model would not provide an easier way to predict the net operations and maintenance cost saved. Therefore, current estimating techniques are an accurate way to estimate the net operations and maintenance cost saved from an EMCS.

The energy saved model had 16.7 percent of the actual values within plus or minus 20 percent of the predicted values. Additional variables that could be included in the model to improve its predictive capability include the number and size of motors controlled, the hours of operation required for each motor, the number and size of heating units, the type of functions performed on each piece of equipment, age of the facility, and type of construction. As with the other models, gathering this information requires a detailed study of each facility similar to the A-E feasibility studies and a model would not provide an easier way to predict the energy saved. Therefore, current estimating techniques are an accurate way to estimate the energy saved from an EMCS.

## Summary

Each of the conclusions reached in this chapter is summarized below:

1. Current EMCS provide an average payback of less than six years (4.6 years) and an average annual energy

saved of greater than 23 MBtu/$1000 invested (160 MBtu/$1000 invested).

2. Future EMCS should be able to exceed the criteria of six years payback and 23 MBtu/$1000 invested.

3. The A-E feasibility studies accurately predict the EMCS cost and savings.

4. The A-E firms should become more accurate as they gain more experience in predicting the EMCS cost and savings.

5. The size and type of a facility (what it is used for) contribute the most information to the EMCS cost and savings in the models used.

6. Heating and electric rates should not be considered as major factors in determining whether an EMCS should be installed in a facility.

7. Multiple Linear Regression models with the variables chosen cannot be used to accurately predict the EMCS cost and savings.

8. Detailed studies of each facility similar to the A-E feasibility studies are necessary to accurately determine the EMCS cost and savings.

## Chapter 6

## RECOMMENDATIONS

This research effort only considered EMCS currently being monitored and these systems were some of the first ones installed. Therefore, continued monitoring of the cost and savings from the EMCS is needed to insure that future EMCS meet the criteria used to justify the cost to install the systems. Also, many of the operational EMCS have only start-stop functions being performed, which made the determination of energy savings easy to accomplish (power consumption multiplied by time off). Future EMCS will be using more sophisticated techniques that will require meters to calculate the actual energy savings. Measurement of the actual results is essential to provide feedback to the designers, users, and Congress. The designers use this information in order to make better estimates of the savings for future installations. The users need this information to make decisions on what functions to include in studies and how to refine system operation to get the most savings. Congress requires this information to make better decisions on what projects to fund.

The use of A-E feasibility studies or a study similar to this type should be continued in order to

provide accurate predictions of the EMCS cost and savings. The use of simple models such as developed in this research effort or generalized criteria such as $500 per point do not provide accurate predictions of the EMCS cost and savings necessary to make decisions on where to install EMCS and what functions to include. The Building Energy Audit Pilot Program (9) method of using a computer simulation program to estimate the cost and savings may provide an accurate method. However, even this program requires a detailed study of each facility similar to the A-E feasibility studies (some of the A-E firms used computer simulation programs to develop their estimates). The simulation method should be examined and tested against the operational EMCS to determine how accurate it is. This method has several advantages such as:

1. The ability to change equipment.

2. The ability to modify functions performed by an EMCS to determine the results.

3. The ability to determine the synergistic effects of many functions performed in the same facility.

While simulations on a computer would provide useful information, experimenting with an actual EMCS would provide more valuable information. More experimenting with actual systems is needed to determine the full capabilities of the EMCS. Also, reports on experiments, both failures and successes, should be circulated to other

bases to prevent duplication of a long process of trial and error. Throughout this research effort there appeared to be a crossfeed of information between the major commands; however, it was an informal crossfeed. There should be a formal system set up to provide a central authority on EMCS, and other energy conservation practices, to screen manufacturer's systems and claims, provide a point of contact for current information, and distribute results of experiments to the bases that need the information.

The actual cost and savings from EMCS approved based on feasibility studies should be compared directly to the feasibility studies estimates to verify the conclusions made in this research effort. Different A-E firms can be judged on how accurate their estimates are in order to insure that only the best available firms are used to make the studies and design the systems.

GLOSSARY

## GLOSSARY

Air conditioning unit: A piece of equipment designed to lower the temperature and/or control the humidity of the air in a facility.

Air handling unit: A piece of equipment designed to move air in a facility.

Analog: A continuous range within predefined limits.

Appropriated projects: Projects for which Congress has set aside funds.

Approved projects: Projects whose concept has been accepted by Congress as worthwhile.

Architect-Engineer firms: Private engineering design firms.

Binary: Two possible states, either on or off, flow or no-flow, etc.

Btu: British thermal unit. The amount of energy required to raise the temperature one pound of water one degree Fahrenheit.

Categorical variable: A variable used to distinguish between different non-quantifiable terms in Multiple Linear Regression.

Confidence interval: An interval estimate of a variable with a stated level of confidence, i.e. 90 percent confidence.

Dependent variable: A variable whose value depends upon other conditions (independent variable values).

Design (project): The specific procedures and equipment that are to be used to get the desired results of the project.

Effectiveness (EMCS): The amount of energy saved in MBtu per $1000 invested.

Efficiency (EMCS payback): The number of years in which the cumulative net operations and maintenance cost saved equals the investment cost.

EMCS: Energy Monitoring and Control System. A system designed to monitor and control remote mechanical, electrical, utility, and life-safety building systems from a central location.

F-distribution: A statistical distribution of the random variable $S_1^2/S_2^2$ where populations 1 and 2 are normally distributed.

Feasibility study: A detailed economic and energy analysis of the cost and savings possible from installing an EMCS.

Hardwired system: A system in which the operation can only be changed by rewiring the electronic components.

Induced voltages: Voltages generated in electric wires from lightning strikes near the wires.

MBtu: One million Btu's.

Mean Square Error (MSE) and Mean Square Regression (MSR): In Multiple Linear Regression, with $y_i$ representing the dependent data value for case i, $\hat{y}_i$ representing the estimate of the dependent data value for case i, p representing the number of independent variables plus one, and n representing the number of cases:

$$MSE = \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{n-p}$$

$$MSR = \frac{\sum_{i=1}^{n} \left[ y_i - \frac{\sum_{i=1}^{n} y_i}{n} \right]^2}{p-1}$$

Microprocessor: A type of computer usually based on processing words that are eight bits long. The main functions are usually contained on one integrated circuit.

Minicomputer: A type of computer usually based on processing words that are 16 bits long. The main functions are usually contained in many different integrated circuits.

Multiplexing: A process in which many different electronic signals can be sent over one communications line. This is usually accomplished by electronically selecting the desired signal to send.

Pneumatic lines: Air lines used in mechanical systems to control the operation of the systems.

Software programmable system: A system in which the operation can be changed by changing the polarity of the components without rewiring the components.

Standard deviation: A measure of the variability of a set of data elements about their mean value.

Students t-distribution: A statistical distribution of the variable

$$\frac{\bar{X} - U_x}{s/\sqrt{n}}$$

where the population random variables x and $\bar{X}$ are normally distributed.

APPENDIX A

LISTING OF
FEASIBILITY STUDY DATA AND
OPERATIONAL DATA

AD-A060 552 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 15/5
ENERGY MONITORING AND CONTROL SYSTEMS EFFECTIVENESS AND EFFICIE--ETC(U)
SEP 78 A A ALCHIAN, T J BURNS
UNCLASSIFIED AFIT-LSSR-7-78B NL

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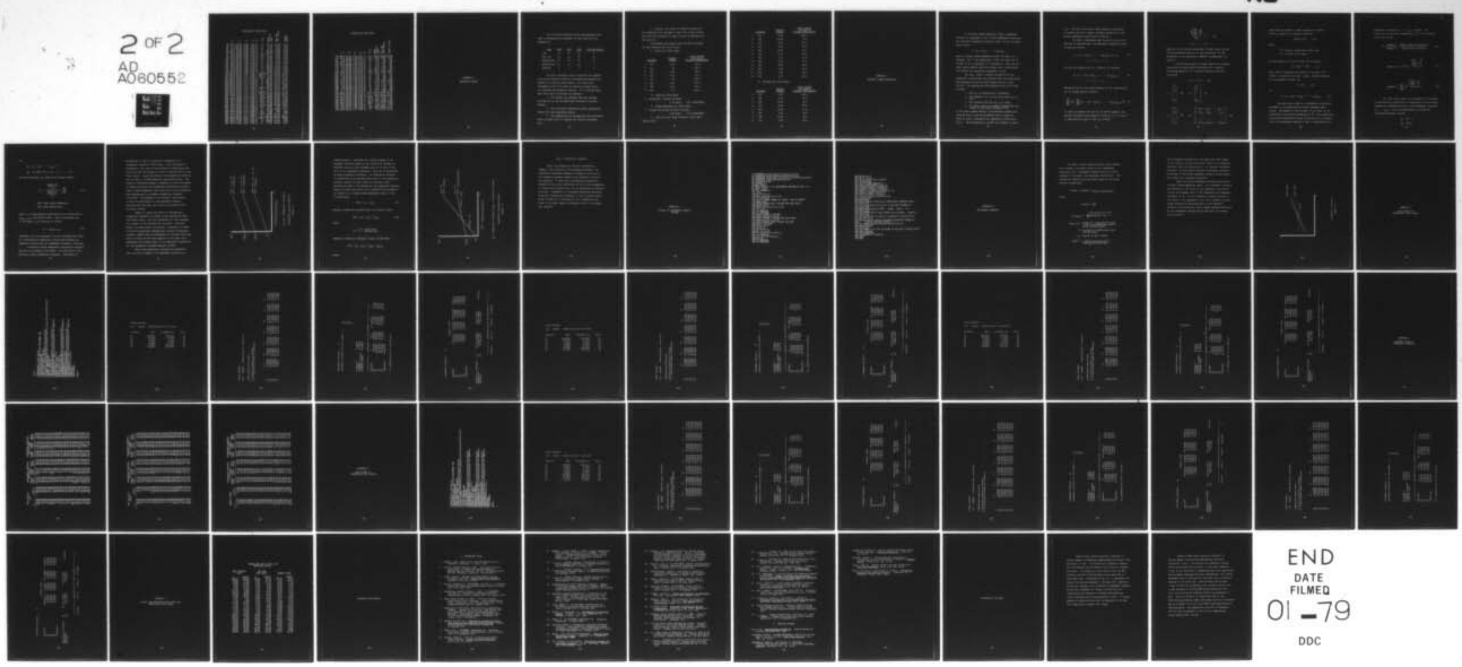

END
DATE
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FEASIBILITY STUDY DATA

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_1X_5$ | EMCS INITIAL COST | NET O&M COST SAVED | ENERGY SAVED |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 162.4 | 30.00 | 2.00 | 4.46 | 0. | 0. | 51.40 | 23.30 | 8.92 |
| 20 | 21.7 | 30.00 | 2.90 | 4.46 | 0. | 0. | 23.10 | 2.50 | 0.81 |
| 30 | 8.7 | 30.00 | 2.00 | 4.46 | 0. | 0. | 8.70 | 3.90 | 1.56 |
| 40 | 58.7 | 30.00 | 2.00 | 4.46 | 0. | 0. | 38.40 | 14.80 | 5.58 |
| 50 | 215.5 | 30.00 | 2.00 | 4.46 | 0. | 0. | 102.90 | 19.20 | 5.81 |
| 60 | 30.9 | 30.00 | 2.00 | 4.46 | 0. | 0. | 28.60 | 6.80 | 2.47 |
| 70 | 34.3 | 30.00 | 2.00 | 4.46 | 1. | 34.3 | 44.10 | 11.80 | 4.81 |
| 80 | 83.2 | 30.00 | 2.00 | 4.46 | 0. | 0. | 46.20 | 3.40 | 1.39 |
| 90 | 60.0 | 30.00 | 2.00 | 4.46 | 0. | 0. | 21.60 | 16.80 | 6.85 |
| 100 | 18.0 | 29.00 | 1.20 | 4.49 | 0. | 0. | 10.50 | 1.90 | 0.54 |
| 110 | 34.7 | 29.00 | 1.20 | 4.49 | 0. | 0. | 68.10 | 10.40 | 3.48 |
| 120 | 49.0 | 29.00 | 1.20 | 4.49 | 0. | 0. | 33.20 | 3.70 | 1.11 |
| 130 | 68.2 | 29.00 | 1.20 | 4.49 | 0. | 0. | 122.50 | 47.60 | 8.37 |
| 140 | 20.0 | 29.00 | 1.20 | 4.49 | 0. | 0. | 82.20 | 11.80 | 3.04 |
| 150 | 89.0 | 29.00 | 1.20 | 4.49 | 0. | 0. | 95.30 | 13.20 | 3.52 |
| 160 | 55.9 | 29.00 | 1.20 | 4.49 | 0. | 0. | 25.30 | 8.80 | 2.34 |
| 170 | 892.8 | 29.00 | 1.20 | 4.49 | 1. | 892.8 | 595.10 | 153.00 | 21.49 |
| 180 | 189.2 | 18.50 | 1.17 | 6.58 | 1. | 189.2 | 76.50 | 18.30 | 12.38 |
| 190 | 129.0 | 18.50 | 1.17 | 6.58 | 1. | 129.0 | 62.00 | 14.60 | 10.15 |
| 200 | 129.9 | 18.50 | 1.17 | 6.58 | 0. | 0. | 39.50 | 13.70 | 9.42 |
| 210 | 209.4 | 18.50 | 1.17 | 6.58 | 0. | 0. | 130.50 | 17.50 | 12.10 |
| 220 | 544.4 | 18.50 | 1.17 | 6.58 | 0. | 0. | 194.00 | 44.10 | 29.46 |
| 230 | 229.9 | 18.50 | 1.17 | 6.58 | 0. | 0. | 84.50 | 21.70 | 14.36 |
| 240 | 101.2 | 18.50 | 1.17 | 6.58 | 0. | 0. | 50.50 | 13.00 | 8.80 |
| 250 | 356.3 | 18.50 | 1.17 | 6.58 | 1. | 356.3 | 82.10 | 65.10 | 48.82 |
| 260 | 26.4 | 18.50 | 1.17 | 6.58 | 0. | 0. | 32.00 | 15.30 | 11.21 |
| 270 | 263.3 | 18.50 | 1.17 | 6.58 | 1. | 263.3 | 111.90 | 56.10 | 41.16 |
| 280 | 154.4 | 18.50 | 1.17 | 6.58 | 1. | 154.4 | 45.30 | 29.30 | 21.58 |
| 290 | 75.3 | 18.50 | 1.17 | 6.58 | 1. | 75.3 | 98.60 | 35.80 | 25.97 |
| 300 | 52.3 | 18.50 | 1.17 | 6.58 | 1. | 52.3 | 16.50 | 12.90 | 9.44 |
| 310 | 45.7 | 18.50 | 1.17 | 6.58 | 1. | 45.7 | 79.60 | 23.40 | 17.46 |
| 320 | 64.9 | 18.50 | 1.17 | 6.58 | 1. | 64.9 | 16.50 | 11.20 | 8.70 |
| 330 | 79.1 | 18.50 | 1.17 | 6.58 | 1. | 79.1 | 78.60 | 34.50 | 24.85 |
| 340 | 73.8 | 18.50 | 1.17 | 6.58 | 1. | 73.8 | 64.90 | 24.20 | 16.27 |
| 350 | 31.5 | 18.50 | 1.17 | 6.58 | 1. | 31.5 | 78.50 | 7.50 | 5.56 |
| 360 | 35.0 | 18.50 | 1.17 | 6.58 | 0. | 0. | 15.50 | 12.00 | 8.71 |
| 370 | 52.9 | 18.50 | 1.17 | 6.58 | 0. | 0. | 25.40 | 9.80 | 7.18 |
| 380 | 39.7 | 18.50 | 1.17 | 6.58 | 1. | 39.7 | 9.80 | 7.40 | 5.63 |
| 390 | 39.3 | 18.50 | 1.17 | 6.58 | 1. | 39.3 | 23.80 | 10.10 | 7.65 |
| 400 | 61.8 | 18.50 | 1.17 | 6.58 | 0. | 0. | 113.50 | 23.50 | 16.11 |
| 410 | 600.0 | 22.00 | 2.67 | 6.55 | 1. | 600.0 | 900.00 | 450.00 | 99.90 |
| 420 | 63.6 | 14.00 | 2.01 | 4.06 | 0. | 0. | 61.30 | 11.70 | 0.90 |
| 430 | 105.6 | 14.00 | 2.01 | 4.05 | 0. | 0. | 156.00 | 23.00 | 1.80 |
| 440 | 52.5 | 14.00 | 2.01 | 4.05 | 0. | 0. | 78.00 | 10.80 | 0.84 |

# OPERATIONAL EMCS DATA

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_1X_5$ | EMCS INITIAL COST | NET O&M COST SAVED | ENERGY SAVED |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 600.0 | 18.29 | 1.50 | 6.27 | 0. | 0. | 150.0 | 85.84 | 54.88 |
| 110 | 83.8 | 25.00 | 1.40 | 5.10 | 1. | 83.8 | 40.0 | 8.83 | 4.10 |
| 120 | 8.0 | 25.00 | 1.40 | 5.10 | 0. | 0. | 5.5 | .72 | .33 |
| 130 | 22.5 | 25.00 | 1.40 | 5.10 | 0. | 0. | 10.8 | .62 | .29 |
| 140 | 24.6 | 25.00 | 1.40 | 5.10 | 0. | 0. | 5.5 | 1.27 | .59 |
| 150 | 14.1 | 25.00 | 1.40 | 5.10 | 0. | 0. | 5.5 | .13 | .06 |
| 160 | 9.6 | 25.00 | 1.49 | 5.10 | 0. | 0. | 16.3 | 1.84 | .86 |
| 170 | 4.1 | 25.00 | 1.40 | 5.10 | 0. | 0. | 21.7 | 1.40 | .65 |
| 180 | 47.2 | 25.00 | 1.40 | 5.10 | 1. | 47.2 | 60.0 | 6.41 | 2.98 |
| 190 | 15.5 | 25.60 | 1.49 | 5.10 | 1. | 15.5 | 16.9 | 9.90 | 4.91 |
| 200 | 14.0 | 25.60 | 1.49 | 5.10 | 0. | 0. | 15.2 | .30 | .59 |
| 210 | 3.9 | 25.60 | 1.49 | 5.10 | 0. | 0. | 4.2 | .85 | .51 |
| 220 | 7.2 | 25.60 | 1.49 | 5.10 | 0. | 0. | 7.8 | .87 | .63 |
| 230 | 34.8 | 25.60 | 1.49 | 5.10 | 0. | 0. | 37.9 | 1.08 | 1.62 |
| 240 | 16.4 | 25.60 | 1.49 | 5.10 | 0. | 0. | 17.9 | 4.72 | 2.63 |
| 250 | 10.3 | 25.60 | 1.49 | 5.10 | 0. | 0. | 11.2 | 1.47 | 1.00 |
| 260 | 9.9 | 25.60 | 1.49 | 5.10 | 0. | 0. | 11.2 | 1.07 | .80 |
| 270 | 8.0 | 25.60 | 1.49 | 5.10 | 0. | 0. | 8.7 | 1.42 | .90 |
| 280 | 11.0 | 25.60 | 1.49 | 5.10 | 0. | 0. | 11.9 | 1.33 | .96 |
| 290 | 14.4 | 25.60 | 1.49 | 5.10 | 0. | 0. | 15.7 | 1.80 | 1.27 |
| 300 | 124.4 | 25.60 | 1.49 | 5.10 | 1. | 124.4 | 135.5 | 60.30 | 30.78 |
| 310 | 37.2 | 25.87 | 1.85 | 4.49 | 0. | 0. | 43.2 | 9.66 | 4.01 |
| 320 | 218.5 | 25.87 | 1.85 | 4.49 | 1. | 218.5 | 33.3 | 50.52 | 22.15 |
| 330 | 20.0 | 25.87 | 1.85 | 4.49 | 1. | 20.0 | 13.3 | 4.02 | .80 |
| 340 | 30.7 | 25.87 | 1.85 | 4.49 | 1. | 30.7 | 40.0 | 8.06 | 3.62 |
| 350 | 154.4 | 25.87 | 1.85 | 4.49 | 1. | 154.4 | 19.7 | 40.69 | 16.80 |
| 360 | 50.7 | 25.87 | 1.85 | 4.49 | 1. | 50.7 | 8.8 | 4.10 | 1.54 |
| 370 | 143.4 | 25.87 | 1.85 | 4.49 | 0. | 0. | 64.9 | 19.41 | 7.73 |
| 380 | 60.0 | 25.87 | 1.85 | 4.49 | 1. | 60.0 | 33.0 | 30.58 | 12.91 |
| 390 | 318.0 | 22.10 | 1.17 | 6.58 | 0. | 0. | 79.0 | 24.14 | 12.76 |

# APPENDIX B

# ESCALATION RATES

The following escalation rates (percentages) were used in determining the payback for each facility (32: Appendix D):

| Item | 1978 | 1979 | 1980 | 1981 and beyond |
|---|---|---|---|---|
| Coal | 10 | 10 | 10 | 5 |
| Fuel Oil | 16 | 16 | 16 | 8 |
| Electricity | 16 | 16 | 16 | 8 |
| Natural Gas | 15 | 15 | 15 | 7 |
| Manpower | 5 | 5 | 5 | 5 |

The basic procedure used to calculate the payback involved an iterative method to successively approach the payback on a month by month basis. All costs were considered to be FY 77 costs to provide an equal basis for applying the escalation factors. The following steps were then used to calculate the payback:

1. The energy cost savings, O&M cost savings, and O&M cost to run the EMCS were converted to monthly figures.

2. The costs were escalated by their appropriate factors for each successive month.

3. The cummulative net savings was then calculated month by month until it equaled the initial investment cost.

4. Finally, the number of months required for the cummulative net savings to equal the initial investment cost was converted to years to give the payback for the facility.

The payback and energy saved per $1000 invested for each facility are listed below.

A. Robins Air Force Base:

| Building | | Payback (years) | Annual Energy Saved/$1000 Invested (MBtu/$1000) |
|---|---|---|---|
| 1. | 125 | 3.72 | 92.8 |
| 2. | 140 | .68 | 680.2 |
| 3. | 158 | 2.99 | 60.2 |
| 4. | 165 | 4.42 | 90.5 |
| 5. | 169 | .50 | 852.8 |
| 6. | 226 | 2.00 | 175.0 |
| 7. | 640 | 2.91 | 119.1 |
| 8. | 645 | .07 | 391.2 |

B. Lowry Air Force Base:

1. Accounting + Finance Building

1.67 years 365.9 MBtu/$1000

C. Wright-Patterson Air Force Base:

1. Foreign Technology Division Building

2.84 years 167.9 MBtu/$1000

D. Luke Air Force Base (Honeywell Delta 2000 system only):

| | Building | Payback (Years) | Annual Energy Saved/$1000 Invested (MBtu/$1000) |
|---|---|---|---|
| 1. | 121 | 2.22 | 290.5 |
| 2. | 343 | 22.29 | 38.8 |
| 3. | 411 | 5.10 | 121.4 |
| 4. | 416 | 7.96 | 80.8 |
| 5. | 700 | 18.45 | 42.7 |
| 6. | 750 | 4.12 | 146.9 |
| 7. | 799 | 7.10 | 89.3 |
| 8. | 859 | 8.89 | 71.4 |
| 9. | 905 | 6.04 | 103.4 |
| 10. | 962 | 7.98 | 80.7 |
| 11. | 1525 | 7.84 | 80.9 |
| 12. | 1130 | 2.82 | 227.2 |

E. Williams Air Force Base:

| | Building | Payback (Years) | Annual Energy Saved/$1000 Invested (MBtu/$1000) |
|---|---|---|---|
| 1. | 237 | 3.74 | 102.5 |
| 2. | 234 | 5.75 | 60.0 |
| 3. | 558 | 10.60 | 26.9 |
| 4. | 571 | 3.60 | 107.3 |
| 5. | 664 | 18.54 | 10.9 |
| 6. | 795 | 6.59 | 52.8 |
| 7. | 786 | 10.00 | 30.0 |
| 8. | 785 | 6.88 | 48.2 |

# APPENDIX C

# MULTIPLE LINEAR REGRESSION

In Multiple Linear Regression (MLR) a dependent variable is regressed on two or more independent variables. The resultant regression produces a model of the following form (16:54):

$$y = b_0 + b_1x_1 + \cdots + b_{p-1}x_{p-1}$$

While in Simple Linear Regression (SLR) the model is a straight line in two dimensions, in MLR the model can be thought of as a hyperplane in p dimensions. MLR uses the Least Square Method (LSM) to estimate the b coefficients that define the regression hyperplane (16:55).

The best, linear, unbiased estimators of the regression coefficients are obtained under the appropriate MLR assumptions when the Least Square Method is used (16:55). The appropriate MLR assumptions are as follows (41:265):

1. Each $y_i$ is statistically independent.
2. The expected value of the error term ($e_i$) is zero.
3. The variance ($\sigma^2$) for all $x_i$ is equal.
4. The error terms are normally distributed with a mean of zero and a variance of $\sigma^2$.

In the Least Squares Method, the difference between the observed value y and the estimated value $\hat{y}$ using the model is used to determine the regression coefficients ($b_j$'s). This difference is called the residual or error

($e_i$). The sum of the error terms squared is minimized to produce the best, linear, unbiased estimators of the actual regression coefficients (16:54-55).

In order to determine what the error term is for each set of observations, the population regression model is used as follows:

$$Y_i = B_0 + B_1 X_{1,i} + \cdots + B_{p-1} X_{p-1,i} + e_i \qquad (1)$$

$$i = 1, 2, \ldots, n$$

Solving this equation for $e_i$, equation (1) becomes:

$$e_i = Y_i - (B_0 + B_1 X_{1,i} + \cdots + B_{p-1} X_{p-1,i}) \qquad (2)$$

$$i = 1, 2, \ldots, n$$

Taking the sum of the errors squared for all observations the following equation results:

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} [Y_i - (B_0 + B_1 X_{1,i} + \cdots + B_{p-1} X_{p-1,i})]^2 \qquad (3)$$

In order to minimize the sum of the errors squared, the partial derivative with respect to each $b_j$ ($j = 0$ to $p-1$) is taken and set equal to zero as follows:

$$\frac{\partial\left(\sum_{i=1}^{n} e_i^2\right)}{\partial b_j} = 0 \qquad (4)$$

$$j = 0, 1, \ldots, p-1$$

Equation (4) is called the system of normal equations and "the simultaneous solution to this system are the LSM estimators of the population regression parameters $B_j$'s [16:55]."

Solving this system of normal equations is greatly simplified by using matrix techniques and a computer. Converting equation (1) to matrix notation yields the following:

$$Y = B \cdot X + e \qquad (5)$$

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{bmatrix} \quad (6) \qquad B = \begin{bmatrix} B_0 \\ B_1 \\ \cdot \\ \cdot \\ \cdot \\ B_{p-1} \end{bmatrix} \quad (7)$$

$$e = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_n \end{bmatrix} \quad (8) \qquad X = \begin{bmatrix} 1 & X_{1,1} & X_{2,1} & \cdots & X_{n,1} \\ 1 & X_{1,2} & X_{2,2} & \cdots & X_{n,2} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ 1 & X_{1,p-1} & X_{2,p-1} & \cdots & X_{n,p-1} \end{bmatrix} \quad (9)$$

Converting the system of normal equations to matrix notation, equation (4) becomes (16:56-61):

$$(X^T X)\vec{b} = X^T Y \qquad (10)$$

where:

$X^T$ = matrix X transposed (B:28), and
$\vec{b}$ = b vector of $b_j$ terms.

Solving equation (1) for $\vec{b}$ yields the following:

$$\vec{b} = (X^T X)^{-1} (X^T Y) \qquad (11)$$

where $(X^T X)^{-1}$ indicates the inverse of the term $(X^T X)$ (18:60). Therefore, the best, linear, unbiased estimate of the dependent variable is:

$$\hat{y} = \vec{b}\, X \qquad (12)$$

or:

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_{p-1} x_{p-1} \qquad (13)$$

The next step in MLR is to determine how accurate the model is in predicting the actual dependent data values. One measure of the accuracy of the model is the coefficient of multiple determination, $R^2$. The coefficient of multiple determination gives the proportion of variability in the dependent variable y that is explained by the

independent variables $X_1, \ldots, X_{p-1}$ (25:408). The coefficient of multiple determination, $R^2$, is calculated as follows (16:63):

$$R^2 = \frac{\text{Sample EV}}{\text{Sample TV}} = \frac{\text{Sample Explained Variation}}{\text{Sample Total Variation}} \tag{14}$$

$$\text{Sample EV} = b^T(X^TY) - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \tag{15}$$

$$\text{Sample TV} = \sum_{i=1}^{n} y_i^2 - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \tag{16}$$

The final step in MLR is to determine if the model is statistically significant in explaining the relationship between the dependent variable y and independent variables $X_1, \ldots, X_{p-1}$. This is accomplished by testing the following hypothesis (16:65):

$$H_o: R^2 = 0$$

$$H_a: R^2 \neq 0$$

or:

$$H_o\colon\ B_1 = B_2 = \cdots = B_{p-1} = 0$$

$$H_a\colon\ \text{at least one } B_j \neq 0,\ j = 1, \ldots, p-1$$

The test statistic, $F_o$, used is as follows (16:65):

$$F_o = \frac{\dfrac{\text{Sample EV}}{p-1}}{\dfrac{\text{Sample UV}}{n-p}} = \frac{MSR}{MSE} \tag{17}$$

MSR = Mean Square Regression

MSE = Mean Square Error

where $F_o$ is approximately distributed as an F-distribution ($F_{\alpha, p-1, n-p}$) (25:342-372, 549). With a one-tailed test to the right, $H_o$ is rejected if (16:65):

$$F_o > F_{\alpha, p-1, n-p} \tag{18}$$

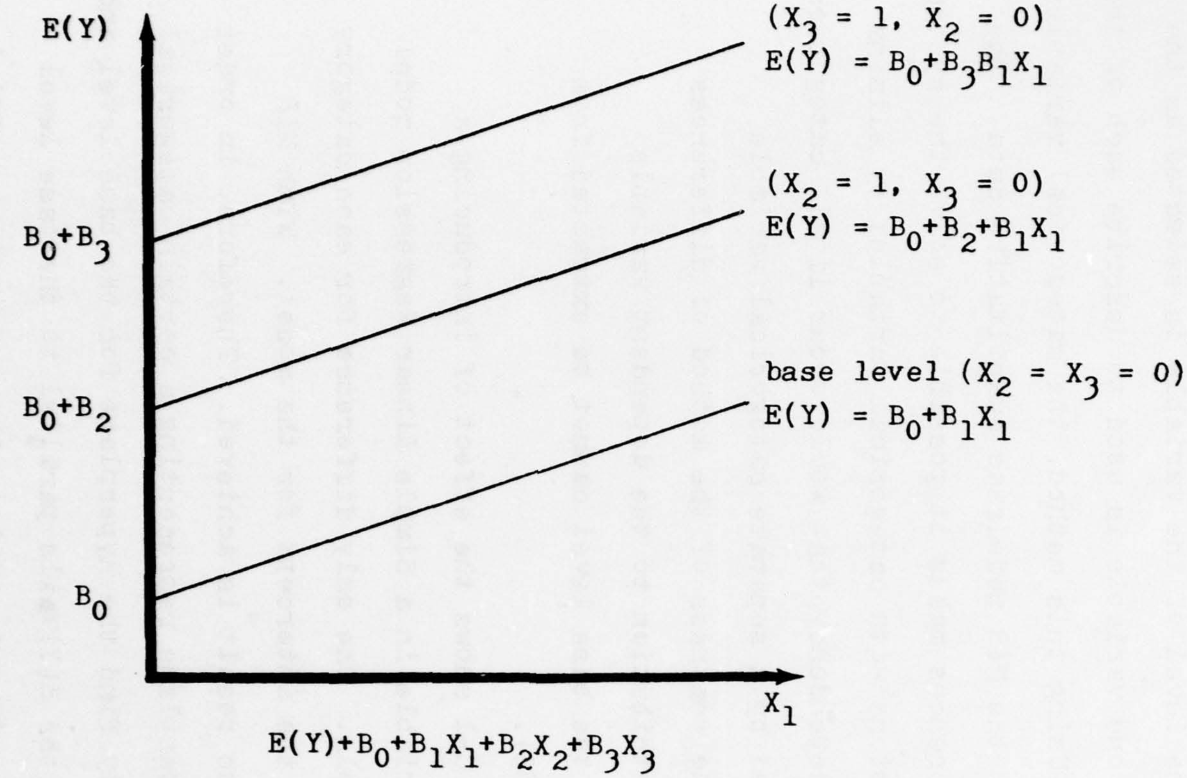
Therefore, if $H_o$ is rejected it can be concluded that there is a statistically significant relationship between the dependent variable and the independent variables (16:64-65).

In Multiple Linear Regression, qualitative variables may also be included in the models. The qualitative variables are called categorical variables. The method of

differences is used to encode the information in a categorical variable in MLR models. With the method of differences, one level of the variable is selected as the base level and one variable is used to describe each of the other levels. Using this method, the categorical variables can be coded in the MLR models as quantitative data. The method of differences makes it possible to solve the system of normal equations with categorical variables by eliminating a linear dependency that would occur if all categories were represented by a separate categorical variable (16:78-88). The weakness of the method of differences is that the contribution to the dependent variable resulting from the base level cannot be extracted from the model (16:82).

Figure C-1 shows the effect of introducing a categorical variable in a Simple Linear Regression model with three levels. The only difference for each category is a change in the intercept for the model. With MLR models, the same result is achieved. Therefore, in order to find the hyperplane representing a certain categorical variable, simply find the hyperplane for the base level and shift it along the E(Y) axis parallel to the base level hyperplane by an amount equal to the regression coefficient for the categorical variable desired (21:300).

When using categorical variables by themselves, they only show a change in the dependent variable by a




$X_2$, $X_3$: Categorical variables

Categorical Variable Effects

Figure C-1

constant amount. There may be a varying change in the dependent variable caused by the interaction between the different levels in each category and one or more of the ratio level independent variables. This can be determined by using interaction variables. An interaction variable is constructed by multiplying each level in the categorical variable, except the base level, by the ratio level variable believed to be effected by the categorical variable. Figure C-2 shows the effect of an interaction and categorical variable on a Simple Linear Regression model of the following type:

$$E(Y) = B_0 + B_1X_1 \tag{19}$$

Adding a categorical variable with two levels we have:

$$E(Y) = B_0 + B_1X_1 + B_2X_2 \tag{20}$$

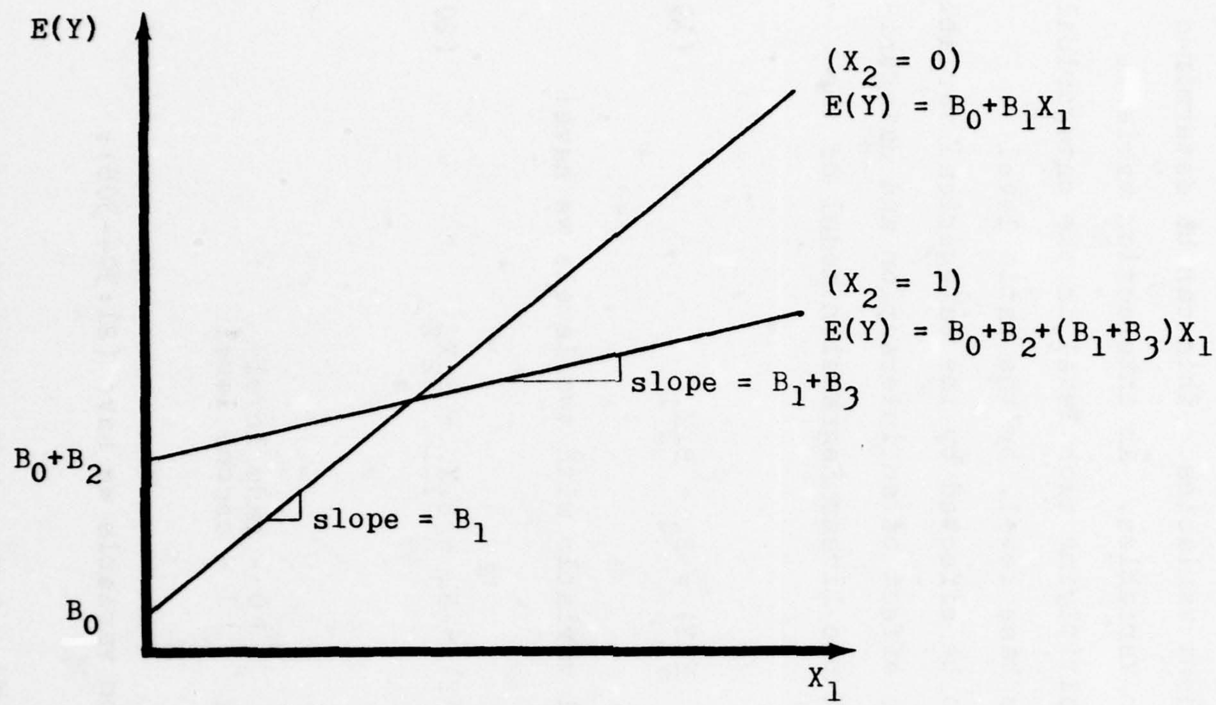
where:

$$X_2 = \begin{cases} 0 \text{ - base level} \\ 1 \text{ - second level} \end{cases}$$

Adding an interaction variable we have (21:304-306):

$$E(Y) = B_0 + B_1X_1 + B_2X_2 + B_3X_1X_2$$

where:




$$E(Y) = B_0+B_1X_1+B_2X_2+B_3X_1X_2$$

$X_2$: Categorical variable; $X_1X_2$: Interaction variable

Interaction Variable Effects

Figure C-2

$X_1X_2$ = interaction variable.

While the categorical variable represents a change in the intercept of the regression surface, the interaction variables represent a change in the slope of the regression surface caused by the different levels in the category. If there are no differences between the different levels, the coefficient (b's) for the categorical or interaction variables will not be statistically different from zero. Therefore, by including interaction variables along with categorical variables, it can be quickly determined if there is a difference in the intersection and slope of the model based on different levels of a categorical variable.

# APPENDIX D

## LISTING OF CONFIDENCE INTERVAL PROGRAM

```
DIMENSION C(15,15),B(15),X(30,15),P(15)
DIMENSION Q(30),EYH(30),VEYH(30),VYH(30)
DIMENSION CIUEYH(30),CILEYH(30),CIUYH(30),CILYH(30)
DIMENSION Y(30),HEYH(30),HYH(30)
CHARACTER ANS*1
INTEGER LN
REAL MSE,T
PRINT,"ENTER # OF INDEPENDENT VARIABLES (MAX 14)"
READ  100,N
100 FORMAT(V)
M=N+1
DO 110 I=1,M
READ 100,(C(I,J),J=1,M)
110 CONTINUE
PRINT,"ENTER NUMBER OF CASES - MAX 30 CASES"
READ 100,K
PRINT,"ENTER NEW X VALUES FOR EACH CASE"
DO 20 I=1,K
READ 100,(X(I,J+1),J=1,N)
X(I,1)=1.
20 CONTINUE
21 CONTINUE
PRINT,"ENTER B VALUES"
READ 100,(B(I),I=1,M)
PRINT,"ENTER Y VALUES FOR EACH CASE"
READ 100,(Y(I),I=1,K)
PRINT,"ENTER YOUR T-VALUE AND MSE"
READ 100,T,MSE
DO 60 L=1,K
EYH(L)=0.
DO 50 I=1,M
DO  40 J=1,M
P(I)=P(I)+C(I,J)*X(L,J)
40 CONTINUE
Q(L)=Q(L)+P(I)*X(L,I)
P(I)=0.
50 CONTINUE
60 CONTINUE
```

```
DO 80 J=1,K
DO 70 I=1,M
EYH(J)=EYH(J)+X(J,I)*B(I)
70 CONTINUE
VEYH(J)=SQRT(MSE*Q(J))
VYH(J)=SQRT(MSE*(1.+Q(J)))
CIUEYH(J)=EYH(J)+T*VEYH(J)
CILEYH(J)=EYH(J)-T*VEYH(J)
HEYH(J)=(CIUEYH(J)-CILEYH(J))/2.
CIUYH(J)=EYH(J)+T*VYH(J)
CILYH(J)=EYH(J)-T*VYH(J)
HYH(J)=(CIUYH(J)-CILYH(J))/2.
80 CONTINUE
PRINT 260
260 FORMAT(///,24X,2(1X,"CONFIDENCE INTERVAL",3X))
PRINT 270
270 FORMAT(29X,"ON U(Y/X):",12X,"ON Y=Y(NEXT)")
PRINT 280
280 FORMAT(24X,2("UPPER   LOWER   HALF-   "))
PRINT 290
290 FORMAT(4X,"Y",9X,"Y(EST)",4X,2("LIMIT   LIMIT")
PRINT 295
295 FORMAT(9("-"),2X,9("-"),3X,21("-"),3X,21("-"))
DO 330 I=1,K
PRINT 340,Y(I),EYH(I),CIUEYH(I),CILEYH(I),HEYH(I),
&      CIUYH(I),CILYH(I),HYH(I)
340 FORMAT(F10.2,1X,F10.2,2X,6(F7.2,1X))
330 CONTINUE
PRINT 335
335 FORMAT (///,"DO YOU WANT TO USE NEW Y VALUES Y/N?")
READ 350,ANS
350 FORMAT(A1)
IF(ANS.EQ."Y") GOTO 21
STOP
END
```

## APPENDIX E

## CONFIDENCE INTERVALS

In order to draw inferences about a new observation, y(next), for given values of the independent variables (x's), confidence intervals about the point estimate of Y(y(next)) are developed (25:541-543). The confidence intervals are developed using the following formula (21:208-230):

$$Y(\text{next}) = y(\text{next}) \pm t_{(\alpha/2,n-p)}s_{(y(\text{next}))}$$

where:

$$y(\text{next}) = X_h^T\vec{b}$$

$$s_{(y(\text{next}))} = \sqrt{MSE(X_h^T(X^TX)^{-1}X_h + 1)}$$

$t_{(\alpha/2,n-p)}$ = student's t-distribution where n and p are parameters used to build the MLR models

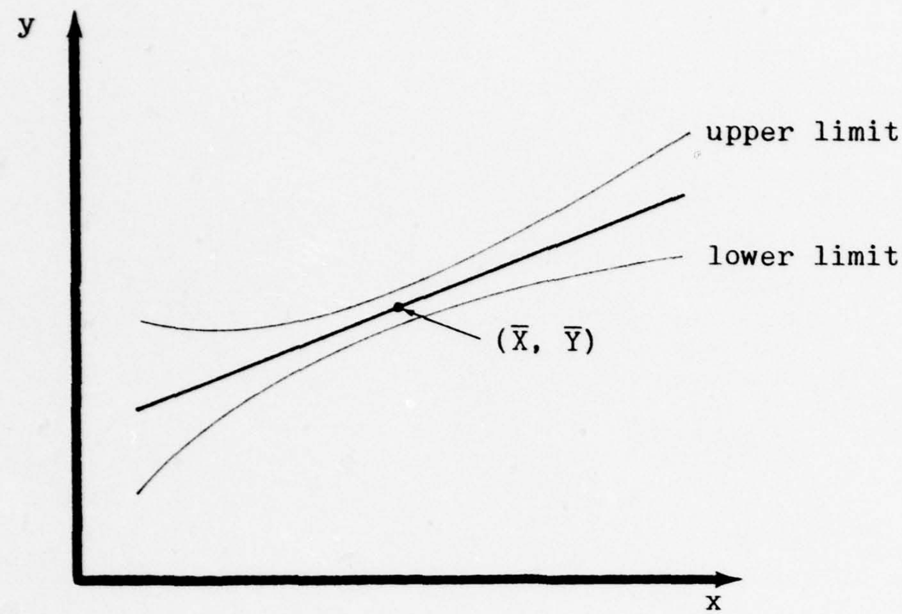
$\vec{b}$ = vector of b coefficients from the MLR model

$X_h$ = vector of new x values

$(X^TX)^{-1}$ = C matrix developed while building the MLR model.

The confidence intervals give the upper and lower ranges of the interval in which the actual value of the dependent variable Y will be located with $1 - \alpha$ percent confidence. Therefore, in developing 90 percent confidence intervals, 90 percent of the actual dependent variable values should fall within the confidence intervals.

Figure E-1 shows confidence intervals drawn about a Simple Linear Regression model. The confidence intervals are narrowest at the point on the regression line identified by the average value of the independent and dependent variables $(\overline{X}, \overline{Y})$. As the confidence intervals extend to the limits of the regression line, the confidence interval widens because the estimated value of the dependent variable is more variable (has a larger standard deviation) as the independent variable moves away from its average value (25:541).




Confidence Intervals

Figure E-1

APPENDIX F

SPSS OUTPUT OF
FEASIBILITY STUDY MODELS

```
LIST

100##S,R(ZL) :,8,16;;,16
110$:IDENT:WP1149, AFIT/LSG TOM BURNS 78B
120$:SELECT:SPSS/SPSS
130RUN NAME;THESIS PROJECT
140VARIABLE LIST;X1,X2,X3,X4,X5,X6,X7,X8,X9
150INPUT FORMAT;FIXED(1X,F5.1,1X,3(F5.2,1X),F2.0,1X,F5.1,1X,3(F6.2,1X))
160INPUT MEDIUM;CARD
170N OF CASES;44
180REGRESSION;VARIABLES=X1,X2,X3,X4,X5,X6,X7/
190;REGRESSION=X7 WITH X1,X2,X3,X4,X5,X6 (2) RESID=0/
200STATISTICS;1,2,4,5,6
210READ INPUT DATA
220$:SELECTA:THESIS5
230REGRESSION;VARIABLES=X1,X2,X3,X4,X5,X6,X8/
240;REGRESSION=X8 WITH X1,X2,X3,X4,X5,X6 (2) RESID=0/
250STATISTICS;1,2,4,5,6
260REGRESSION;VARIABLES=X1,X2,X3,X4,X5,X6,X9/
270;REGRESSION=X9 WITH X1,X2,X3,X4,X5,X6 (2) RESID=0/
280STATISTICS;1,2,4,5,6
290FINISH
300$:ENDJOB

READY
```

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

| VARIABLE | MEAN | STANDARD DEV | CASES |
|---|---|---|---|
| X1 | 129.7591 | 172.2281 | 44 |
| X2 | 22.5341 | 5.7652 | 44 |
| X3 | 1.4366 | 0.4162 | 44 |
| X4 | 5.5934 | 1.0967 | 44 |
| X5 | 0.3864 | 0.4925 | 44 |
| X6 | 70.9295 | 169.8138 | 44 |
| X7 | 93.6932 | 153.6851 | 44 |

THESIS PROJECT

FILE    NONAME    (CREATION DATE = 08/02/78)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 |
|---|---|---|---|---|---|---|---|
| X1 | 1.00000 | -0.02982 | 0.05242 | 0.13015 | 0.25084 | 0.83999 | 0.80317 |
| X2 | -0.02982 | 1.00000 | 0.33941 | -0.68360 | -0.35281 | -0.01713 | 0.00594 |
| X3 | 0.05242 | 0.33941 | 1.00000 | -0.56954 | -0.24643 | 0.04056 | 0.30287 |
| X4 | 0.13015 | -0.68360 | -0.56954 | 1.00000 | 0.53953 | 0.14015 | 0.05003 |
| X5 | 0.25084 | -0.35281 | -0.24643 | 0.53953 | 1.00000 | 0.53248 | 0.24302 |
| X6 | 0.83999 | -0.01713 | 0.04056 | 0.14015 | 0.53248 | 1.00000 | 0.79878 |
| X7 | 0.80317 | 0.00594 | 0.30287 | 0.05003 | 0.24302 | 0.79878 | 1.00000 |

```
DEPENDENT VARIABLE..     X7

VARIABLE(S) ENTERED ON STEP NUMBER  1..     X1
                                            X2
                                            X3
                                            X4
                                            X5
                                            X6

MULTIPLE R              0.88922
R SQUARE                0.79071
ADJUSTED R SQUARE       0.75677
STANDARD ERROR         75.79458
```

----------------- VARIABLES IN THE EQUATION ------------------

| VARIABLE | B | BETA | STD ERROR B | F |
|---|---|---|---|---|
| X1 | 0.25700 | 0.28801 | 0.14636 | 3.083 |
| X2 | -0.25233 | -0.00947 | 2.78107 | 0.008 |
| X3 | 126.92256 | 0.34369 | 34.42591 | 13.593 |
| X4 | 30.90572 | 0.22055 | 18.96394 | 2.656 |
| X5 | -60.71189 | -0.19458 | 39.38144 | 2.377 |
| X6 | 0.55699 | 0.61545 | 0.17366 | 10.287 |
| (CONSTANT) | -305.22325 | | | |

ALL VARIABLES ARE IN THE EQUATION

DEPENDENT VARIABLE.. X7

SUMMARY TABLE

| VARIABLE | MULTIPLE R | R SQUARE | RSQ CHANGE | SIMPLE R |
|---|---|---|---|---|
| X1 | 0.80317 | 0.64508 | 0.64508 | 0.80317 |
| X2 | 0.80373 | 0.64598 | 0.00089 | 0.00594 |
| X3 | 0.84691 | 0.71725 | 0.07128 | 0.30287 |
| X4 | 0.85311 | 0.72780 | 0.01055 | 0.05003 |
| X5 | 0.85588 | 0.73252 | 0.00472 | 0.24302 |
| X6 | 0.88922 | 0.79071 | 0.05819 | 0.79878 |
| (CONSTANT) | | | | |

| ANALYSIS OF VARIANCE | DF | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| REGRESSION | 6. | 803062.98310 | 133843.83052 | 23.29818 |
| RESIDUAL | 37. | 212558.28332 | 5744.81847 | |

------------- VARIABLES NOT IN THE EQUATION -------------

| VARIABLE | BETA IN | PARTIAL | TOLERANCE | F |
|---|---|---|---|---|

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

| VARIABLE | MEAN | STANDARD DEV | CASES |
|---|---|---|---|
| X1 | 129.7591 | 172.2281 | 44 |
| X2 | 22.5341 | 5.7652 | 44 |
| X3 | 1.4366 | 0.4162 | 44 |
| X4 | 5.5934 | 1.0967 | 44 |
| X5 | 0.3864 | 0.4925 | 44 |
| X6 | 70.9295 | 169.8138 | 44 |
| X8 | 31.1227 | 69.1295 | 44 |

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

| | X1 | X2 | X3 | X4 | X5 | X6 | X8 |
|---|---|---|---|---|---|---|---|
| X1 | 1.00000 | -0.02982 | 0.05242 | 0.13015 | 0.25084 | 0.83999 | 0.67613 |
| X2 | -0.02982 | 1.00000 | 0.33941 | -0.68360 | -0.35281 | -0.01713 | -0.02019 |
| X3 | 0.05242 | 0.33941 | 1.00000 | -0.56954 | -0.24643 | 0.04056 | 0.35628 |
| X4 | 0.13015 | -0.68360 | -0.56954 | 1.00000 | 0.53953 | 0.14015 | 0.14782 |
| X5 | 0.25084 | -0.35281 | -0.24643 | 0.53953 | 1.00000 | 0.53248 | 0.29787 |
| X6 | 0.83999 | -0.01713 | 0.04056 | 0.14015 | 0.53248 | 1.00000 | 0.72965 |
| X8 | 0.67613 | -0.02019 | 0.35628 | 0.14782 | 0.29787 | 0.72965 | 1.00000 |

DEPENDENT VARIABLE..     X8

VARIABLE(S) ENTERED ON STEP NUMBER  1..     X1
X2
X3
X4
X5
X6

| | |
|---|---|
| MULTIPLE R | 0.86901 |
| R SQUARE | 0.75517 |
| ADJUSTED R SQUARE | 0.71547 |
| STANDARD ERROR | 36.87449 |

------------------ VARIABLES IN THE EQUATION ------------------

| VARIABLE | B | BETA | STD ERROR B | F |
|---|---|---|---|---|
| X1 | 0.00633 | 0.01578 | 0.07120 | 0.008 |
| X2 | 1.18366 | 0.09871 | 1.35340 | 0.765 |
| X3 | 90.47906 | 0.54468 | 16.74840 | 29.184 |
| X4 | 33.99106 | 0.53926 | 9.22606 | 13.574 |
| X5 | -31.01828 | -0.22100 | 19.15929 | 2.621 |
| X6 | 0.30047 | 0.73810 | 0.08449 | 12.648 |
| (CONSTANT) | -325.80725 | | | |

ALL VARIABLES ARE IN THE EQUATION

DEPENDENT VARIABLE..     X8

SUMMARY TABLE

| VARIABLE | MULTIPLE R | R SQUARE | RSQ CHANGE | SIMPLE R |
|---|---|---|---|---|
| X1 | 0.67613 | 0.45715 | 0.45715 | 0.67613 |
| X2 | 0.67613 | 0.45715 | 0.00000 | -0.02019 |
| X3 | 0.75764 | 0.57402 | 0.11686 | 0.35628 |
| X4 | 0.81420 | 0.66292 | 0.08890 | 0.14782 |
| X5 | 0.81944 | 0.67148 | 0.00857 | 0.29787 |
| X6 | 0.86901 | 0.75517 | 0.08369 | 0.72965 |
| (CONSTANT) | | | | |

| ANALYSIS OF VARIANCE | DF | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| REGRESSION | 6. | 155182.31593 | 25863.71932 | 19.02124 |
| RESIDUAL | 37. | 50309.94137 | 1359.72815 | |

------------- VARIABLES NOT IN THE EQUATION -------------

| VARIABLE | BETA IN | PARTIAL | TOLERANCE | F |
|---|---|---|---|---|

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

| VARIABLE | MEAN | STANDARD DEV | CASES |
|---|---|---|---|
| X1 | 129.7591 | 172.2281 | 44 |
| X2 | 22.5341 | 5.7652 | 44 |
| X3 | 1.4366 | 0.4162 | 44 |
| X4 | 5.5934 | 1.0967 | 44 |
| X5 | 0.3864 | 0.4925 | 44 |
| X6 | 70.9295 | 169.8138 | 44 |
| X9 | 12.6932 | 17.0772 | 44 |

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

| | X1 | X2 | X3 | X4 | X5 | X6 | X9 |
|---|---|---|---|---|---|---|---|
| X1 | 1.00000 | -0.02982 | 0.05242 | 0.13015 | 0.25084 | 0.83999 | 0.63961 |
| X2 | -0.02982 | 1.00000 | 0.33941 | -0.68360 | -0.35281 | -0.01713 | -0.24074 |
| X3 | 0.05242 | 0.33941 | 1.00000 | -0.56954 | -0.24643 | 0.04056 | 0.12093 |
| X4 | 0.13015 | -0.68360 | -0.56954 | 1.00000 | 0.53953 | 0.14015 | 0.45490 |
| X5 | 0.25084 | -0.35281 | -0.24643 | 0.53953 | 1.00000 | 0.53248 | 0.45906 |
| X6 | 0.83999 | -0.01713 | 0.04056 | 0.14015 | 0.53248 | 1.00000 | 0.66216 |
| X9 | 0.63961 | -0.24074 | 0.12093 | 0.45490 | 0.45906 | 0.66216 | 1.00000 |

```
DEPENDENT VARIABLE..      X9

VARIABLE(S) ENTERED ON STEP NUMBER  1..    X1
                                           X2
                                           X3
                                           X4
                                           X5
                                           X6

MULTIPLE R              0.85770
R SQUARE                0.73564
ADJUSTED R SQUARE       0.69277
STANDARD ERROR          9.46558

----------------- VARIABLES IN THE EQUATION -----------------

VARIABLE            B          BETA      STD ERROR B        F
X1              0.01912      0.19279      0.01828        1.094
X2              0.28219      0.09526      0.34741        0.660
X3             19.09615      0.46536      4.29927       19.729
X4             11.38993      0.73147      2.36830       23.130
X5             -1.85084     -0.05338      4.91814        0.142
X6              0.04112      0.40889      0.02169        3.595
(CONSTANT)    -89.48248

ALL VARIABLES ARE IN THE EQUATION
```

DEPENDENT VARIABLE..    X9

SUMMARY TABLE

| VARIABLE | MULTIPLE R | R SQUARE | RSQ CHANGE | SIMPLE R |
|---|---|---|---|---|
| X1 | 0.63961 | 0.40910 | 0.40910 | 0.63961 |
| X2 | 0.67696 | 0.45828 | 0.04918 | -0.24074 |
| X3 | 0.69890 | 0.48846 | 0.03018 | 0.12093 |
| X4 | 0.83565 | 0.69831 | 0.20985 | 0.45490 |
| X5 | 0.84259 | 0.70996 | 0.01165 | 0.45906 |
| X6 | 0.85770 | 0.73564 | 0.02568 | 0.66216 |
| (CONSTANT) | | | | |

| ANALYSIS OF VARIANCE | DF | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| REGRESSION | 6. | 9225.07464 | 1537.51244 | 17.16029 |
| RESIDUAL | 37. | 3315.09385 | 89.59713 | |

------------- VARIABLES NOT IN THE EQUATION --------------

| VARIABLE | BETA IN | PARTIAL | TOLERANCE | F |
|---|---|---|---|---|

## APPENDIX G

## COMPUTER OUTPUT OF CONFIDENCE INTERVALS

| EMCS INITIAL COST | | CONFIDENCE INTERVAL ON U(Y/X): | | | CONFIDENCE INTERVAL ON Y=Y(NEXT) | | |
|---|---|---|---|---|---|---|---|
| Y | Y(EST) | UPPER LIMIT | LOWER LIMIT | HALF-WIDTH | UPPER LIMIT | LOWER LIMIT | HALF-WIDTH |
| 150.00 | 228.52 | 316.89 | 140.16 | 88.37 | 320.95 | 136.10 | 92.43 |
| 40.00 | 31.28 | 84.67 | -22.11 | 53.39 | 169.85 | -107.29 | 138.57 |
| 5.50 | 25.84 | 59.38 | -7.71 | 33.55 | 158.04 | -106.36 | 132.20 |
| 10.80 | 29.56 | 60.26 | -1.13 | 30.70 | 161.07 | -101.94 | 131.51 |
| 5.50 | 30.10 | 60.36 | -0.16 | 30.26 | 161.51 | -101.30 | 131.41 |
| 5.50 | 27.40 | 59.78 | -4.97 | 32.38 | 159.31 | -104.51 | 131.91 |
| 16.30 | 26.25 | 59.49 | -7.00 | 33.24 | 158.37 | -105.88 | 132.12 |
| 21.70 | 24.83 | 59.10 | -9.44 | 34.27 | 157.22 | -107.55 | 132.39 |
| 60.00 | 1.49 | 52.82 | -49.84 | 51.33 | 139.28 | -136.30 | 137.79 |
| 16.90 | -13.04 | 39.05 | -65.14 | 52.09 | 125.03 | -151.12 | 138.08 |
| 15.20 | 38.65 | 70.96 | 6.34 | 32.31 | 170.54 | -93.24 | 131.89 |
| 4.20 | 36.05 | 70.30 | 1.80 | 34.25 | 168.43 | -96.33 | 132.38 |
| 7.80 | 36.90 | 70.53 | 3.27 | 33.63 | 169.12 | -95.32 | 132.22 |
| 37.90 | 43.99 | 71.88 | 16.11 | 27.89 | 174.87 | -86.88 | 130.88 |
| 17.90 | 39.27 | 71.10 | 7.44 | 31.83 | 171.04 | -92.51 | 131.78 |
| 11.20 | 37.70 | 70.73 | 4.66 | 33.03 | 169.77 | -94.37 | 132.07 |
| 11.20 | 37.60 | 70.71 | 4.48 | 33.11 | 169.69 | -94.50 | 132.09 |
| 8.70 | 37.11 | 70.58 | 3.63 | 33.48 | 169.29 | -95.08 | 132.18 |
| 11.90 | 37.88 | 70.78 | 4.98 | 32.90 | 169.91 | -94.16 | 132.04 |
| 15.70 | 38.75 | 70.98 | 6.52 | 32.23 | 170.62 | -93.12 | 131.87 |
| 135.50 | 75.60 | 134.27 | 16.92 | 58.68 | 216.29 | -65.09 | 140.69 |
| 43.20 | 71.38 | 101.78 | 40.98 | 30.40 | 202.82 | -60.05 | 131.44 |
| 33.30 | 178.97 | 265.31 | 92.63 | 86.34 | 333.26 | 24.68 | 154.29 |
| 13.30 | 17.39 | 79.07 | -44.29 | 61.68 | 159.36 | -124.58 | 141.97 |
| 40.00 | 26.10 | 87.24 | -35.04 | 61.14 | 167.84 | -115.64 | 141.74 |
| 19.70 | 126.79 | 198.55 | 55.04 | 71.76 | 273.42 | -19.84 | 146.63 |
| 8.80 | 42.38 | 103.17 | -18.41 | 60.79 | 183.97 | -99.21 | 141.59 |
| 64.90 | 98.68 | 114.68 | 82.68 | 16.00 | 225.54 | -28.19 | 126.87 |
| 33.00 | 49.95 | 110.87 | -10.97 | 60.92 | 191.59 | -91.69 | 141.64 |
| 79.00 | 122.79 | 174.61 | 70.96 | 51.83 | 239.69 | 5.89 | 116.90 |

| NET O&M COST SAVED | | CONFIDENCE INTERVAL ON U(Y/X): | | | CONFIDENCE INTERVAL ON Y=Y(NEXT) | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Y | Y(EST) | UPPER LIMIT | LOWER LIMIT | HALF-WIDTH | UPPER LIMIT | LOWER LIMIT | HALF-WIDTH |
| 85.84 | 48.48 | 91.47 | 5.49 | 42.99 | 93.45 | 3.52 | 44.97 |
| 8.83 | -1.50 | 24.48 | -27.48 | 25.98 | 65.92 | -68.92 | 67.42 |
| 0.72 | 3.86 | 20.18 | -12.46 | 16.32 | 68.18 | -60.46 | 64.32 |
| 0.62 | 3.95 | 18.89 | -10.98 | 14.93 | 67.93 | -60.03 | 63.98 |
| 1.27 | 3.97 | 18.69 | -10.76 | 14.72 | 67.89 | -59.96 | 63.93 |
| 0.13 | 3.90 | 19.65 | -11.85 | 15.75 | 68.07 | -60.28 | 64.17 |
| 1.84 | 3.87 | 20.04 | -12.30 | 16.17 | 68.15 | -60.41 | 64.28 |
| 1.40 | 3.84 | 20.51 | -12.84 | 16.67 | 68.24 | -60.57 | 64.41 |
| 6.41 | -12.73 | 12.24 | -37.70 | 24.97 | 54.31 | -79.76 | 67.04 |
| 9.90 | -13.60 | 11.74 | -38.94 | 25.34 | 53.58 | -80.78 | 67.18 |
| 0.30 | 12.75 | 28.47 | -2.97 | 15.72 | 76.92 | -51.41 | 64.17 |
| 0.85 | 12.69 | 29.35 | -3.98 | 16.66 | 77.09 | -51.72 | 64.40 |
| 0.87 | 12.71 | 29.07 | -3.65 | 16.36 | 77.03 | -51.62 | 64.33 |
| 1.08 | 12.88 | 26.45 | -0.68 | 13.57 | 76.56 | -50.79 | 63.67 |
| 4.72 | 12.77 | 28.25 | -2.72 | 15.49 | 76.88 | -51.34 | 64.11 |
| 1.47 | 12.73 | 28.80 | -3.34 | 16.07 | 76.98 | -51.53 | 64.25 |
| 1.07 | 12.73 | 28.83 | -3.38 | 16.11 | 76.99 | -51.54 | 64.26 |
| 1.42 | 12.71 | 29.00 | -3.57 | 16.29 | 77.02 | -51.59 | 64.31 |
| 1.33 | 12.73 | 28.74 | -3.27 | 16.01 | 76.97 | -51.50 | 64.24 |
| 1.80 | 12.75 | 28.43 | -2.93 | 15.68 | 76.91 | -51.40 | 64.16 |
| 60.30 | 19.81 | 48.36 | -8.74 | 28.55 | 88.26 | -48.64 | 68.45 |
| 9.66 | 25.06 | 39.85 | 10.27 | 14.79 | 89.00 | -38.89 | 63.94 |
| 58.52 | 60.84 | 102.84 | 18.83 | 42.00 | 135.90 | -14.23 | 75.06 |
| 4.02 | -0.06 | 29.95 | -30.07 | 30.01 | 69.01 | -69.13 | 69.07 |
| 8.06 | 3.22 | 32.97 | -26.53 | 29.75 | 72.18 | -65.74 | 68.96 |
| 40.69 | 41.17 | 76.08 | 6.26 | 34.91 | 112.51 | -30.16 | 71.34 |
| 4.10 | 9.36 | 38.93 | -20.22 | 29.57 | 78.24 | -59.53 | 68.88 |
| 19.41 | 25.73 | 33.51 | 17.94 | 7.78 | 87.45 | -35.99 | 61.72 |
| 30.58 | 12.21 | 41.85 | -17.43 | 29.64 | 81.12 | -56.70 | 68.91 |
| 24.14 | 31.89 | 57.10 | 6.67 | 25.21 | 88.76 | -24.99 | 56.87 |

| ENERGY SAVED | | CONFIDENCE INTERVAL ON U(Y/X): | | | CONFIDENCE INTERVAL ON Y=Y(NEXT) | | |
|---|---|---|---|---|---|---|---|
| Y | Y(EST) | UPPER LIMIT | LOWER LIMIT | HALF-WIDTH | UPPER LIMIT | LOWER LIMIT | HALF-WIDTH |
| 54.88 | 27.20 | 38.24 | 16.17 | 11.04 | 38.75 | 15.66 | 11.54 |
| 4.10 | 5.59 | 12.25 | -1.08 | 6.67 | 22.89 | -11.72 | 17.31 |
| 0.33 | 2.54 | 6.73 | -1.65 | 4.19 | 19.05 | -13.97 | 16.51 |
| 0.29 | 2.82 | 6.65 | -1.01 | 3.83 | 19.24 | -13.60 | 16.42 |
| 0.59 | 2.86 | 6.64 | -0.92 | 3.78 | 19.27 | -13.55 | 16.41 |
| 0.06 | 2.66 | 6.70 | -1.39 | 4.04 | 19.13 | -13.82 | 16.47 |
| 0.86 | 2.57 | 6.72 | -1.58 | 4.15 | 19.07 | -13.93 | 16.50 |
| 0.65 | 2.47 | 6.75 | -1.81 | 4.28 | 19.00 | -14.07 | 16.53 |
| 2.98 | 3.38 | 9.79 | -3.03 | 6.41 | 20.59 | -13.83 | 17.21 |
| 4.91 | 3.36 | 9.87 | -3.15 | 6.51 | 20.60 | -13.88 | 17.24 |
| 0.59 | 4.54 | 8.58 | 0.51 | 4.03 | 21.02 | -11.93 | 16.47 |
| 0.51 | 4.35 | 8.63 | 0.07 | 4.28 | 20.88 | -12.18 | 16.53 |
| 0.63 | 4.41 | 8.61 | 0.21 | 4.20 | 20.93 | -12.10 | 16.51 |
| 1.62 | 4.94 | 8.42 | 1.46 | 3.48 | 21.29 | -11.40 | 16.34 |
| 2.63 | 4.59 | 8.57 | 0.61 | 3.98 | 21.05 | -11.87 | 16.46 |
| 1.00 | 4.47 | 8.60 | 0.35 | 4.13 | 20.97 | -12.02 | 16.49 |
| 0.80 | 4.47 | 8.60 | 0.33 | 4.14 | 20.96 | -12.03 | 16.50 |
| 0.90 | 4.43 | 8.61 | 0.25 | 4.18 | 20.94 | -12.08 | 16.51 |
| 0.96 | 4.49 | 8.60 | 0.38 | 4.11 | 20.98 | -12.00 | 16.49 |
| 1.27 | 4.55 | 8.58 | 0.53 | 4.03 | 21.02 | -11.92 | 16.47 |
| 30.78 | 9.92 | 17.25 | 2.59 | 7.33 | 27.49 | -7.65 | 17.57 |
| 4.01 | 4.99 | 8.79 | 1.19 | 3.80 | 21.41 | -11.42 | 16.41 |
| 22.15 | 15.59 | 26.37 | 4.81 | 10.78 | 34.86 | -3.68 | 19.27 |
| 0.80 | 3.63 | 11.34 | -4.07 | 7.70 | 21.36 | -14.10 | 17.73 |
| 3.62 | 4.28 | 11.91 | -3.36 | 7.64 | 21.98 | -13.42 | 17.70 |
| 16.80 | 11.73 | 20.69 | 2.77 | 8.96 | 30.04 | -6.58 | 18.31 |
| 1.54 | 5.48 | 13.07 | -2.11 | 7.59 | 23.17 | -12.20 | 17.68 |
| 7.73 | 7.02 | 9.02 | 5.02 | 2.00 | 22.87 | -8.82 | 15.84 |
| 12.91 | 6.04 | 13.65 | -1.56 | 7.61 | 23.73 | -11.65 | 17.69 |
| 12.76 | 20.12 | 26.59 | 13.64 | 6.47 | 34.71 | 5.52 | 14.60 |

APPENDIX H

SPSS OUTPUT OF
OPERATIONAL EMCS MODELS

```
100##S,R(ZL) :,8,16;;,16
110$:IDENT:WP1149, AFIT/LSG TOM BURNS 78B
120$:SELECT:SPSS/SPSS
130RUN NAME;THESIS PROJECT
140VARIABLE LIST;X1,X2,X3,X4,X5,X6,X7,X8,X9
150INPUT FORMAT;FIXED(1X,F5.1,1X,F5.2,1X,2(F4.2,1X),F2.0,1X,2(F5.1,1X),
152;2(F5.2,1X))
160INPUT MEDIUM;CARD
170N OF CASES;30
180REGRESSION;VARIABLES=X1,X2,X3,X4,X5,X6,X7,X8,X9/
190;REGRESSION=X7 WITH X1,X2,X3,X4,X5,X6 (2) RESID=0/
200STATISTICS;1,2,4,5,6
210READ INPUT DATA
220$:SELECTA:THESIS1
230REGRESSION;VARIABLES=X1,X2,X3,X4,X5,X6,X7,X8,X9/
240;REGRESSION=X8 WITH X1,X2,X3,X4,X5,X6 (2) RESID=0/
250STATISTICS;1,2,4,5,6
260REGRESSION;VARIABLES=X1,X2,X3,X4,X5,X6,X7,X8,X9/
270;REGRESSION=X9 WITH X1,X2,X3,X4,X5,X6 (2) RESID=0/
280STATISTICS;1,2,4,5,6
290FINISH
300$:ENDJOB

READY

*
```

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

| VARIABLE | MEAN | STANDARD DEV | CASES |
|---|---|---|---|
| X1 | 70.5533 | 123.4031 | 30 |
| X2 | 25.1517 | 1.4753 | 30 |
| X3 | 1.5517 | 0.1939 | 30 |
| X4 | 5.0257 | 0.4687 | 30 |
| X5 | 0.3333 | 0.4795 | 30 |
| X6 | 26.8400 | 53.3204 | 30 |
| X7 | 31.4867 | 35.7617 | 30 |
| X8 | 12.7783 | 20.8939 | 30 |
| X9 | 6.4553 | 11.7009 | 30 |

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 |
|---|---|---|---|---|---|---|---|
| X1 | 1.00000 | -0.84956 | 0.01705 | 0.53294 | 0.05809 | 0.24762 | 0.78315 |
| X2 | -0.84956 | 1.00000 | 0.37204 | -0.80042 | 0.23903 | 0.18703 | -0.64019 |
| X3 | 0.01705 | 0.37204 | 1.00000 | -0.78979 | 0.50574 | 0.43666 | -0.02325 |
| X4 | 0.53294 | -0.80042 | -0.78979 | 1.00000 | -0.44756 | -0.36713 | 0.42453 |
| X5 | 0.05809 | 0.23903 | 0.50574 | -0.44756 | 1.00000 | 0.72405 | 0.17222 |
| X6 | 0.24762 | 0.18703 | 0.43666 | -0.36713 | 0.72405 | 1.00000 | 0.22039 |
| X7 | 0.78315 | -0.64019 | -0.02325 | 0.42453 | 0.17222 | 0.22039 | 1.00000 |
| X8 | 0.85523 | -0.56799 | 0.23596 | 0.22100 | 0.32916 | 0.56023 | 0.81566 |
| X9 | 0.89762 | -0.69144 | 0.13190 | 0.34620 | 0.22150 | 0.42033 | 0.84861 |

DEPENDENT VARIABLE.. X7

VARIABLE(S) ENTERED ON STEP NUMBER 1.. X1
X2
X3
X4
X5
X6

| | |
|---|---|
| MULTIPLE R | 0.84095 |
| R SQUARE | 0.70719 |
| ADJUSTED R SQUARE | 0.63081 |
| STANDARD ERROR | 21.72931 |

------------------ VARIABLES IN THE EQUATION ------------------

| VARIABLE | B | BETA | STD ERROR B | F |
|---|---|---|---|---|
| X1 | 0.63259 | 2.18290 | 0.19283 | 10.762 |
| X2 | 24.35387 | 1.00469 | 12.55430 | 3.763 |
| X3 | -171.62652 | -0.93043 | 87.84145 | 3.817 |
| X4 | -54.97288 | -0.72046 | 42.00014 | 1.713 |
| X5 | 34.26759 | 0.45943 | 14.43757 | 5.634 |
| X6 | -0.46877 | -0.69893 | 0.21547 | 4.733 |
| (CONSTANT) | -81.94375 | | | |

ALL VARIABLES ARE IN THE EQUATION

DEPENDENT VARIABLE.. X7

SUMMARY TABLE

| VARIABLE | MULTIPLE R | R SQUARE | RSQ CHANGE | SIMPLE R |
|---|---|---|---|---|
| X1 | 0.78315 | 0.61332 | 0.61332 | 0.78315 |
| X2 | 0.78459 | 0.61559 | 0.00227 | -0.64019 |
| X3 | 0.79161 | 0.62664 | 0.01105 | -0.02325 |
| X4 | 0.79261 | 0.62824 | 0.00160 | 0.42453 |
| X5 | 0.80432 | 0.64693 | 0.01870 | 0.17222 |
| X6 | 0.84095 | 0.70719 | 0.06026 | 0.22039 |
| (CONSTANT) | | | | |

| ANALYSIS OF VARIANCE | DF | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| REGRESSION | 6. | 26228.34771 | 4371.39129 | 9.25823 |
| RESIDUAL | 23. | 10859.74692 | 472.16291 | |

------------ VARIABLES NOT IN THE EQUATION ------------

| VARIABLE | BETA IN | PARTIAL | TOLERANCE | F |
|---|---|---|---|---|

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

| | X1 | X2 | X3 | X4 | X5 | X6 | X8 |
|---|---|---|---|---|---|---|---|
| X1 | 1.00000 | -0.84956 | 0.01705 | 0.53294 | 0.05809 | 0.24762 | 0.85523 |
| X2 | -0.84956 | 1.00000 | 0.37204 | -0.80042 | 0.23903 | 0.18703 | -0.56799 |
| X3 | 0.01705 | 0.37204 | 1.00000 | -0.78979 | 0.50574 | 0.43666 | 0.23596 |
| X4 | 0.53294 | -0.80042 | -0.78979 | 1.00000 | -0.44756 | -0.36713 | 0.22100 |
| X5 | 0.05809 | 0.23903 | 0.50574 | -0.44756 | 1.00000 | 0.72405 | 0.32916 |
| X6 | 0.24762 | 0.18703 | 0.43666 | -0.36713 | 0.72405 | 1.00000 | 0.56023 |
| X7 | 0.78315 | -0.64019 | -0.02325 | 0.42453 | 0.17222 | 0.22039 | 0.81566 |
| X8 | 0.85523 | -0.56799 | 0.23596 | 0.22100 | 0.32916 | 0.56023 | 1.00000 |
| X9 | 0.89762 | -0.69144 | 0.13190 | 0.34620 | 0.22150 | 0.42033 | 0.98102 |

DEPENDENT VARIABLE..     X8

VARIABLE(S) ENTERED ON STEP NUMBER  1..     X1
X2
X3
X4
X5
X6

| | |
|---|---|
| MULTIPLE R | 0.93083 |
| R SQUARE | 0.86645 |
| ADJUSTED R SQUARE | 0.83161 |
| STANDARD ERROR | 8.57380 |

---------------- VARIABLES IN THE EQUATION ----------------

| VARIABLE | B | BETA | STD ERROR B | F |
|---|---|---|---|---|
| X1 | 0.13584 | 0.80229 | 0.07608 | 3.188 |
| X2 | -0.71295 | -0.05034 | 4.95359 | 0.021 |
| X3 | -0.58217 | -0.00540 | 34.65986 | 0.000 |
| X4 | -5.81185 | -0.13037 | 16.57212 | 0.123 |
| X5 | 0.30394 | 0.00697 | 5.69668 | 0.003 |
| X6 | 0.12556 | 0.32042 | 0.08502 | 2.181 |
| (CONSTANT) | 47.76679 | | | |

ALL VARIABLES ARE IN THE EQUATION

DEPENDENT VARIABLE.. X8

SUMMARY TABLE

| VARIABLE | MULTIPLE R | R SQUARE | RSQ CHANGE | SIMPLE R |
|---|---|---|---|---|
| X1 | 0.85523 | 0.73142 | 0.73142 | 0.85523 |
| X2 | 0.90653 | 0.82179 | 0.09037 | -0.56799 |
| X3 | 0.90653 | 0.82180 | 0.00000 | 0.23596 |
| X4 | 0.91726 | 0.84136 | 0.01956 | 0.22100 |
| X5 | 0.92401 | 0.85379 | 0.01243 | 0.32916 |
| X6 | 0.93083 | 0.86645 | 0.01266 | 0.56023 |
| (CONSTANT) | | | | |

| ANALYSIS OF VARIANCE | DF | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| REGRESSION | 6. | 10969.40197 | 1828.23366 | 24.87054 |
| RESIDUAL | 23. | 1690.73029 | 73.51001 | |

------------- VARIABLES NOT IN THE EQUATION -------------

| VARIABLE | BETA IN | PARTIAL | TOLERANCE | F |
|---|---|---|---|---|

THESIS PROJECT

FILE NONAME (CREATION DATE = 08/02/78)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

| | X1 | X2 | X3 | X4 | X5 | X6 | X9 |
|---|---|---|---|---|---|---|---|
| X1 | 1.00000 | -0.84956 | 0.01705 | 0.53294 | 0.05809 | 0.24762 | 0.89762 |
| X2 | -0.84956 | 1.00000 | 0.37204 | -0.80042 | 0.23903 | 0.18703 | -0.69144 |
| X3 | 0.01705 | 0.37204 | 1.00000 | -0.78979 | 0.50574 | 0.43666 | 0.13190 |
| X4 | 0.53294 | -0.80042 | -0.78979 | 1.00000 | -0.44756 | -0.36713 | 0.34620 |
| X5 | 0.05809 | 0.23903 | 0.50574 | -0.44756 | 1.00000 | 0.72405 | 0.22150 |
| X6 | 0.24762 | 0.18703 | 0.43666 | -0.36713 | 0.72405 | 1.00000 | 0.42033 |
| X7 | 0.78315 | -0.64019 | -0.02325 | 0.42453 | 0.17222 | 0.22039 | 0.84861 |
| X8 | 0.85523 | -0.56799 | 0.23596 | 0.22100 | 0.32916 | 0.56023 | 0.98102 |
| X9 | 0.89762 | -0.69144 | 0.13190 | 0.34620 | 0.22150 | 0.42033 | 1.00000 |

DEPENDENT VARIABLE.. X9

VARIABLE(S) ENTERED ON STEP NUMBER 1.. X1
X2
X3
X4
X5
X6

| | |
|---|---|
| MULTIPLE R | 0.92490 |
| R SQUARE | 0.85545 |
| ADJUSTED R SQUARE | 0.81774 |
| STANDARD ERROR | 4.99535 |

------------------ VARIABLES IN THE EQUATION ------------------

| VARIABLE | B | BETA | STD ERROR B | F |
|---|---|---|---|---|
| X1 | 0.06075 | 0.64071 | 0.04433 | 1.878 |
| X2 | -2.46052 | -0.31023 | 2.88611 | 0.727 |
| X3 | 0.86336 | 0.01431 | 20.19388 | 0.002 |
| X4 | -3.38622 | -0.13564 | 9.65542 | 0.123 |
| X5 | -0.02049 | -0.00084 | 3.31906 | 0.000 |
| X6 | 0.05799 | 0.26426 | 0.04953 | 1.371 |
| (CONSTANT) | 78.18410 | | | |

ALL VARIABLES ARE IN THE EQUATION

DEPENDENT VARIABLE.. X9

SUMMARY TABLE

| VARIABLE | MULTIPLE R | R SQUARE | RSQ CHANGE | SIMPLE R |
|---|---|---|---|---|
| X1 | 0.89762 | 0.80572 | 0.80572 | 0.89762 |
| X2 | 0.90769 | 0.82391 | 0.01819 | -0.69144 |
| X3 | 0.90807 | 0.82459 | 0.00068 | 0.13190 |
| X4 | 0.91615 | 0.83932 | 0.01473 | 0.34620 |
| X5 | 0.92024 | 0.84683 | 0.00751 | 0.22150 |
| X6 | 0.92490 | 0.85545 | 0.00861 | 0.42033 |
| (CONSTANT) | | | | |

| ANALYSIS OF VARIANCE | DF | SUM OF SQUARES | MEAN SQUARE | F |
|---|---|---|---|---|
| REGRESSION | 6. | 3396.48434 | 566.08072 | 22.68536 |
| RESIDUAL | 23. | 573.93202 | 24.95357 | |

------------- VARIABLES NOT IN THE EQUATION -------------

| VARIABLE | BETA IN | PARTIAL | TOLERANCE | F |
|---|---|---|---|---|

APPENDIX I

ACTUAL AND PREDICTED VALUES FROM THE OPERATIONAL EMCS MODELS

## OPERATIONAL EMCS ACTUAL AND PREDICTED VALUES

| EMCS INITIAL COST | | NET O&M COST SAVED | | ENERGY SAVED | |
|---|---|---|---|---|---|
| Y | Y(EST) | Y | Y(EST) | Y | Y(EST) |
| 150.00 | 140.92 | 85.84 | 78.92 | 54.88 | 49.70 |
| 40.00 | 54.26 | 8.83 | 21.70 | 4.10 | 10.54 |
| 5.50 | 11.32 | 0.72 | 0.57 | 0.33 | 1.10 |
| 10.80 | 20.50 | 0.62 | 2.54 | 0.29 | 1.98 |
| 5.50 | 21.82 | 1.27 | 2.83 | 0.59 | 2.10 |
| 5.50 | 15.18 | 0.13 | 1.40 | 0.06 | 1.47 |
| 16.30 | 12.33 | 1.84 | 0.79 | 0.86 | 1.19 |
| 21.70 | 8.85 | 1.40 | 0.04 | 0.65 | 0.86 |
| 60.00 | 48.26 | 6.41 | 12.13 | 2.98 | 6.19 |
| 16.90 | 42.24 | 9.90 | 3.36 | 4.91 | 1.03 |
| 15.20 | 14.29 | 0.30 | 0.91 | 0.59 | 0.06 |
| 4.20 | 7.90 | 0.85 | -0.46 | 0.51 | -0.55 |
| 7.80 | 9.99 | 0.87 | -0.01 | 0.63 | -0.35 |
| 37.90 | 27.45 | 1.08 | 3.73 | 1.62 | 1.33 |
| 17.90 | 15.81 | 4.72 | 1.24 | 2.63 | 0.21 |
| 11.20 | 11.95 | 1.47 | 0.41 | 1.00 | -0.16 |
| 11.20 | 11.69 | 1.07 | 0.35 | 0.80 | -0.19 |
| 8.70 | 10.49 | 1.42 | 0.09 | 0.90 | -0.30 |
| 11.90 | 12.39 | 1.33 | 0.50 | 0.96 | -0.12 |
| 15.70 | 14.54 | 1.80 | 0.96 | 1.27 | 0.09 |
| 135.50 | 60.08 | 60.30 | 31.83 | 30.78 | 13.96 |
| 43.20 | 7.29 | 9.66 | 7.20 | 4.01 | 3.18 |
| 33.30 | 53.82 | 50.52 | 59.57 | 22.15 | 26.85 |
| 13.30 | 21.30 | 4.02 | 7.68 | 0.80 | 3.28 |
| 40.00 | 23.05 | 8.06 | 10.48 | 3.62 | 4.55 |
| 19.70 | 43.32 | 40.69 | 42.81 | 16.80 | 19.24 |
| 8.80 | 26.33 | 4.10 | 15.71 | 1.54 | 6.92 |
| 64.90 | 74.47 | 19.41 | 21.63 | 7.73 | 9.63 |
| 33.00 | 27.85 | 30.58 | 18.14 | 12.91 | 8.03 |
| 79.00 | 94.92 | 24.14 | 36.28 | 12.76 | 21.85 |

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BIOGRAPHICAL SKETCHES

Captain Allen Alchian received a Bachelor of Science degree in Mechanical Engineering from Oregon State University in 1971. He received his commission through ROTC and entered the Air Force in July 1971 as a Weapons Controller. He served his first year at Fort Lee AFS, Virginia, and the following year he was stationed in South East Asia. Returning to the U.S. in September 1973 Captain Alchian was assigned to the Base Civil Engineer, Robins AFB, Georgia, as a construction management engineer. During that assignment he became involved with the installation and operation of Energy Monitoring and Control Systems before being assigned to AFIT. Following graduation Captain Alchian will be assigned to the Base Civil Engineer at Carswell AFB, Texas.

Captain Thomas Burns received a Bachelor of Science degree in Electrical Engineering from Tufts University in 1971. He received his commission through AFROTC and entered the Air Force in 1972 after spending a year at the University of Massachusettes on an educational delay program studying electrical engineering. His initial assignment was at Griffiss AFB, New York, as an electrical engineer in the 416th CES. From Griffiss AFB he spent a year at Thule AB, Greenland, as a contract monitor then he was assigned to HQ AFLC/DEMU Wright-Patterson, AFB, Ohio, as an electrical engineer before his assignment to AFIT. While at HQ AFLC, he represented AFLC at the EMCS Training Workshop, EMCS Guide Specifications Conference, and as a member of the Air Force EMCS Guide Specifications Steering Group. Upon graduation from AFIT in September 1978 he will be assigned to the AF Civil Engineering Center Tyndall AFB, Florida.